RAYTHEON

ELECTRONIC PROGRESS

SEPTEMBER
OCTOBER 1958

Testing a HAWK Radome

In this issue: **SONAR TRANSDUCERS**

ELECTRONIC PROGRESS

Volume III September-October 1958 Number 2

RAYTHEON

Ivan A. Getting ..... *Executive Editor*
James Sterling ..... *Managing Editor*
Marcia Keilson ..... *Editor*
Elmer J. Reese ..... *Art Editor*

ASSOCIATE EDITORS

Nazzareno P. Cedrone
Maynard Laboratory

Lawrence L. Clampitt
Microwave and Power Tube Division

Stanley D. Crane
Santa Barbara Laboratory

Richard P. Curtis
Commercial Equipment Division

Warren T. Eriksen
Research Division

John H. Shea
Semiconductor Division

Herbert N. Washburn
Missile Systems Division

William A. Whitcraft, Jr.
Wayland Laboratory

Robert D. Wilson
Industrial Tube Division

Copyright 1958
Raytheon Manufacturing Company
Waltham 54, Mass.

THE COVER

Our cover picture shows a technician preparing a HAWK radome for boresight-error tests in a specially designed microwave "dark room." The tests will indicate the extent of electromagnetic refraction, with attendant errors in directivity, produced by the radome.

Committees

	CHAIRMAN		CHAIRMAN
Analog Computer	*H. Miller*	Microwave Amplifier	*L. Davis, Jr.*
Ceramics	*S. Blum*	Plastics	*R. Mondano*
Digital Computer	*H. Miller*	Semiconductor Devices Circuit	*J. Mofenson*
Infrared	*H. Letaw, Jr.*	Ultrasonic	*T. Hueter*
Magnetic Amplifiers	*D. McMurtrie*	Welding	*R. Allaire*

Inventions

Congratulations to the following persons for their valuable contributions to Raytheon's portfolio of inventions:

BARRY BROWN ..... Phase Discriminator
KENNETH BROWN ..... Stabilization Generator
EDWARD C. DENCH ..... Microwave Amplifier
KENNETH DOLLINGER ..... Noise Reducing System
R. C. ECKLER, AUSTIN L. MORRILL ..... Decontamination of Welding Electrodes
JAMES R. EISAN ..... Grid Machine Head Spindle
NATHAN FREEDMAN ..... Frequency Selecting Circuit
E. KEON, W. A. ROBBA, R. RUSSELL, G. T. PARISH ..... "Pyrographite"
E. KEON, W. A. ROBBA, R. RUSSELL ..... Carbonaceous Coatings Process
J. M. MARGOLSKEE, T. C. WISENBAKER ..... Accumulator
ERNEST SCHATZ, WARREN WALKER ..... Manufacture of Conductive Plastics

Calendar

NORTHEASTERN UNIVERSITY OFF-CAMPUS COURSES

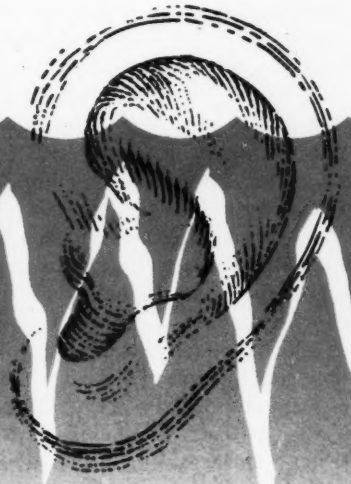
Starting week of Sept. 8

Course	*Place*	*Time*
Theoretical Physics	Training Center	Monday, 6-8 p.m.
Electric Circuit Theory	Bedford Cafeteria	Monday, 6-8 p.m.
Advanced Mathematics	Training Center	Tuesday, 6-8 p.m.
Theory of Microwaves	Training Center	Tuesday, 6-8 p.m.
Servomechanisms Theory	Training Center	Wednesday, 6-8 p.m.
Principles of Microwave Tubes	Training Center	Wednesday, 6-8 p.m.
Transistor Circuit Engineering	Training Center	Wednesday, 6-8 p.m.
Radar Engineering	Training Center	Thursday, 6-8 p.m.
Transients in Linear Systems	Training Center	Friday, 6-8 p.m.

Contents

Sonar Transducers ..... *T. Hueter, J. Renner and N. Serotta* 1
Guided Missile Radomes ..... *F. R. Youngren* 6
Co-operative Education at Raytheon ..... *R. E. Mudgett* 9
Publications and Papers 13
Design Considerations on Transistor High Frequency Amplifiers ..... *R. Martinengo* 14
Patents — Protecting the Unpatentable ..... *B. Lemlein* 18

Sonar Transducers



T. Hueter
J. Renner
N. Serotta
Wayland Laboratory

The word sonar is derived from the words *SO*und *N*avigation *A*nd *R*anging and has come to be applied more generally to all systems using underwater acoustic energy for observation and communication. The observational use of these systems includes primarily the detection of underwater objects and determination of their distance and/or direction. Sonar systems may be broadly classified into two categories: (1) Passive systems for observation of underwater sounds as may be generated by ships' machinery, or the motion of objects through the water; (2) Active systems for observation by echo techniques of objects which may or may not be sources of sound. Direction may be determined in systems of both categories through the use of suitably formed and controlled beam patterns. Distance information is normally obtained directly with echo ranging methods in the active system. Equivalent information for passive systems is more difficult and requires multiple equipment or multiple observation for triangulation techniques.

In all of these systems the key item is the transducer which serves to convert signals from electrical to acoustic energy and vice versa. Additionally the transducer itself or an array of separate transducers in conjunction with associated phasing networks is used to form the appropriate beam pattern for the desired directional characteristics. The capabilities and performance of such systems are to a large degree dependent on an optimal match of the transducer characteristics to the acoustical conditions that prevail in the ocean.

The requirements of sonar equipments are sufficiently varied that almost every conceivable type of transducing mechanism has been utilized at one time or another. The more common types of transducers shall be described here. Before discussing the specific characteristics of these different types, their relative advantages and disadvantages, it appears desirable to review some of the transducer physics which applies to them all.

Transducer Principles

Most sonar transducers employ certain interaction effects that exist between electric or magnetic fields and mechanical deformations in particular classes of solid state materials. Thus, a variation of the magnetic flux produced by an alternating current through a coil wound around a nickel rod will cause a corresponding alternation in the length of the rod or, an alternating voltage applied across a capacitor filled with certain solid dielectrics will cause thickness variations of the dielectric. Such changes in dimension, or motion, if properly coupled to the water can produce pressure waves in the water controlled by the input electrical current or voltage. Conversely vibrations in the water if impressed upon such transducers will induce an electrical AC current in a coil winding or an AC voltage across the capacitor electrodes.

For a high efficiency of conversion of the electrical energy into vibratory mechanical (acoustic) energy, sonar transducers are usually designed to be resonant. The operating frequency is dictated by the acoustical characteristics of the ocean together with other systems considerations. The mechanical resonances of sonar transducers can be visualized in terms of combinations of springs and masses, as in the familiar resonant sys-

tems in mechanics. The electrical analogue to these systems consists of combinations of inductances (for mass), capacitances (for compliance) and resistances (for the radiation load). Mechanical phenomena can thus be described in terms of equivalent electrical circuits. From circuit theory it is known that efficient power transfer from an L-C (or mass-spring) tank circuit to a resistive load requires "tuning" to resonance. Design for efficiency and bandwidth is one of the major endeavors of the transducer engineer.

The elements making up a sonar transducer (active material, loading masses, windings, cement joints, etc.) can be thought of as spring and mass systems, but usually these elements comprise distributed rather than lumped quantities. In the simplest case the transducer element is a rod or bar which acts both as a spring and a mass in itself. Frequently, however, other mass and spring elements are used together with an active electroacoustic material to make a complete resonant system of selected characteristics. In general, the necessary condition for resonance is an equivalent length of one or more half wavelengths.

What factors limit the efficiency of a sonar transducer? The total resistance to motion is determined principally by three factors: the internal friction of the basic electroacoustic material, the damping in the transducer mounting, and the radiation resistance or loading of the medium (water). The lower the percentage of the input power which is needed to overcome the internal and damping losses, the greater the power available to be radiated. One of the objectives of a good transducer design, therefore, is to reduce the damping in relation to the radiation resistance. The internal losses vary among the types of transducers with frequency, power level, etc. and are taken into account in choosing a material for use in a specific application.

The unloaded mechanical Q is often used as a measure of the mechanical quality of a transducer design. If the Q in air is much higher than the Q in water this indicates that the radiation resistance is much greater than the internal and damping resistance. A ratio of 10 to 1 means a *mechanical* efficiency of more than 90%, (which is not unusual for a good design). The mechanical Q in water is a very important characteristic of a sonar transducer. The lower the Q, the wider the bandwidth and, other things being equal, the lower the output. For many sonar applications it is desirable to operate over a fairly wide bandwidth which requires a low mechanical Q. Achievement of a low Q and high efficiency at the same time requires careful design and an optimization of the electroacoustic properties of the known transducer materials. Evidently, different types of transducing mechanisms may be superior for specific uses.

Types of Transducers

Some of the types of transducers used in the early days of sonar have now become nearly obsolete (underwater bells, carbon microphones, electrodynamic Fessenden oscillators, quartz crystal units, etc.). Several other types have found only limited application in sonar up to the present time (electrostatic or capacitor microphones, electrical discharges, explosives, mechanical noise makers, etc.) Thus, we shall here confine ourselves to a short discussion of the most common types of transducers used in modern sonar equipments. They are: (1) magnetostrictive (2) electromagnetic or variable reluctance (3) piezoelectric (4) ferroelectric and (5) electrostrictive.

Magnetostrictive Transducers

Almost all ferromagnetic materials show some magnetostrictive activity. For example, nickel contracts whereas iron and cobalt expand in the direction of the applied magnetic field. Nickel, iron, cobalt and their alloys have sufficiently large magnetostriction to be utilized in sonar transducers. Magnetostrictive ferrites show promise in sonar but as yet are still in the experimental stage as transducer materials. Since magnetostrictive materials will change their dimensions in a definite direction for any applied static magnetic field independent of its polarity, an applied AC field will cause a contraction or expansion of twice the input frequency.

This frequency doubling can be avoided by superimposing the AC signal upon a steady magnetic biasing field which prestretches or precontracts the material. Such a bias field can be supplied by a direct current through a transducer winding, by means of a permanent magnet placed in the magnetic circuit, or by magnetic remanence flux within the material itself.

Magnetostrictive transducers have the advantages of being exceptionally rugged, trouble free and capable of withstanding extreme temperatures and shocks without damage. Being metallic and therefore good heat conductors, they can dissipate large amounts of heat which can easily be removed during high power use. Their impedance can be conveniently adjusted by changing the number of turns in the winding. They are capable of good efficiency as sound generators over a frequency range of about 5–50 kc. As receiving devices or hydrophones they are useful down to a few hundred cycles per second.

Electromagnetic Transducers

Electromagnetic, or, as they are now being more commonly called variable reluctance transducers are used to generate low frequency sound waves in water. These consist essentially of an electromagnet with an air gap. The movable portion of the core is attached to a diaphragm, or piston, which is coupled to the water. A polarizing flux is required to avoid frequency doubling as in the magnetostrictive units. The variable reluctance operation results in considerable non-linearity as well

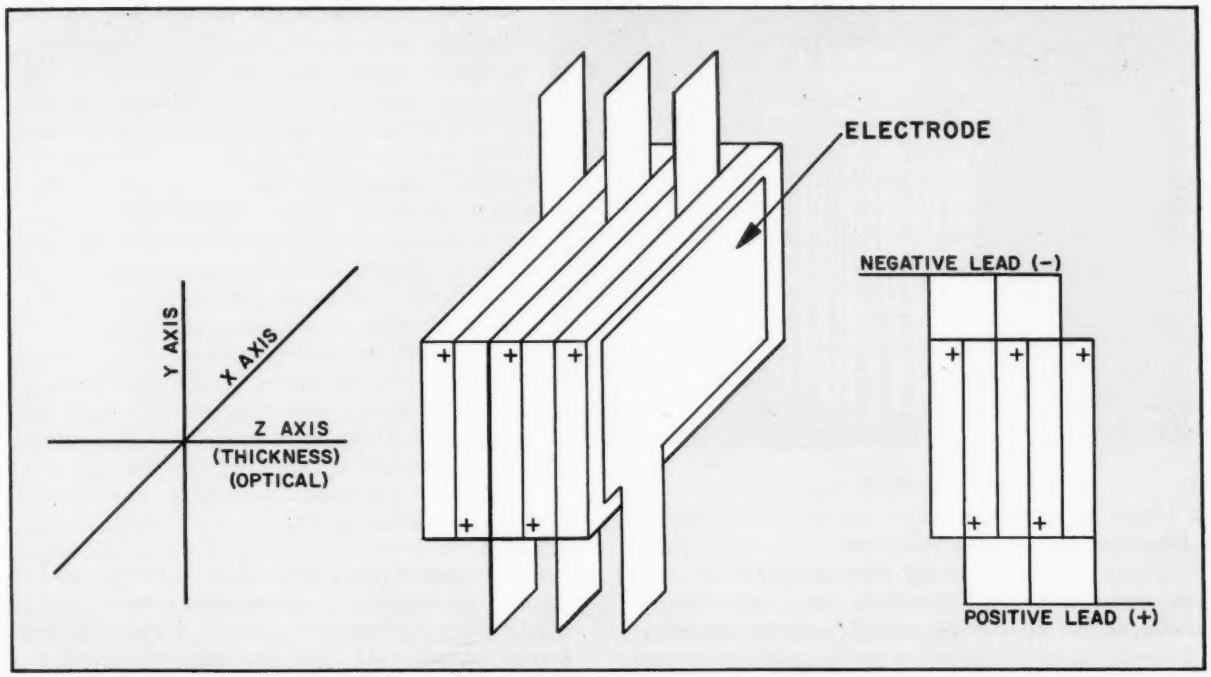


Figure 1

as dependence of performance on hydrostatic pressure. The impedance varies significantly with level so that the characteristics of a given transducer as a receiver depart from those for high level transmission.

The electromagnetic transducers have the advantage of being naturally suited to the production of high acoustic energy in the frequency range below about 2 kc. They can easily be built to have total efficiencies greater than 50%. Narrow bandwidth is an inherent characteristic of most such sonar transducers.

Piezoelectric Transducers

Piezoelectricity is that property of certain crystalline materials which causes them to produce a charge when subjected to a mechanical deformation. Conversely, an applied electrical field produces a mechanical stress. The most commonly used piezoelectric material in modern sonar is ammonium dihydrogen phosphate (ADP), a synthetic crystal. Piezoelectric crystals do not require external polarization since the local fields associated with their molecular structure provide a built-in bias. Figure 1 shows a typical ammonium dihydrogen phosphate crystal with its electrodes. An axis of symmetry exists normal to the axis through its electrodes (optical axis) so that when a voltage is applied across the electrodes a slight structural reorientation occurs, producing changes of the crystal dimensions along the length and width. It is these two dimensions which are usually designed (by themselves, or together with loading masses) to be part of the mechanically resonant system.

A disadvantage of ADP is the cost involved in growing large crystals (greater than about a 3 in. cube). It is generally used in naval sonar equipments at frequencies of 10 kc and above. Its low dielectric constant (about 14) makes it a high impedance material.

Ferroelectric Transducers

Ferroelectricity is similar to piezoelectricity and the two are often lumped together as being part of the piezoelectric group.* There are distinct differences, however, in the properties of ADP and a ferroelectric such as Rochelle salt which is still used in sonar applications because of its great sensitivity (unmatched by any other known material). Rochelle salt, like ADP, does not require any added polarization to enhance its electroacoustic characteristics. Unlike ADP, the performance of Rochelle salt is voltage dependent and limited by hysteresis losses. It is the similarity of its hysteresis effects to the ferromagnetics which has caused the effect to be referred to as ferroelectricity.

Rochelle salt has as its main advantage a remarkably high electroacoustic activity which permits efficient operation over a wide frequency band. It is a low impedance material (dielectric constant greater than 1000).

*For details of the differences, see W. G. Cady, *Piezoelectricity* (McGraw-Hill, New York, 1946).

tems in mechanics. The electrical analogue to these systems consists of combinations of inductances (for mass), capacitances (for compliance) and resistances (for the radiation load). Mechanical phenomena can thus be described in terms of equivalent electrical circuits. From circuit theory it is known that efficient power transfer from an L-C (or mass-spring) tank circuit to a resistive load requires "tuning" to resonance. Design for efficiency and bandwidth is one of the major endeavors of the transducer engineer.

The elements making up a sonar transducer (active material, loading masses, windings, cement joints, etc.) can be thought of as spring and mass systems, but usually these elements comprise distributed rather than lumped quantities. In the simplest case the transducer element is a rod or bar which acts both as a spring and a mass in itself. Frequently, however, other mass and spring elements are used together with an active electroacoustic material to make a complete resonant system of selected characteristics. In general, the necessary condition for resonance is an equivalent length of one or more half wavelengths.

What factors limit the efficiency of a sonar transducer? The total resistance to motion is determined principally by three factors: the internal friction of the basic electroacoustic material, the damping in the transducer mounting, and the radiation resistance or loading of the medium (water). The lower the percentage of the input power which is needed to overcome the internal and damping losses, the greater the power available to be radiated. One of the objectives of a good transducer design, therefore, is to reduce the damping in relation to the radiation resistance. The internal losses vary among the types of transducers with frequency, power level, etc. and are taken into account in choosing a material for use in a specific application.

The unloaded mechanical Q is often used as a measure of the mechanical quality of a transducer design. If the Q in air is much higher than the Q in water this indicates that the radiation resistance is much greater than the internal and damping resistance. A ratio of 10 to 1 means a *mechanical* efficiency of more than 90%, (which is not unusual for a good design). The mechanical Q in water is a very important characteristic of a sonar transducer. The lower the Q, the wider the bandwidth and, other things being equal, the lower the output. For many sonar applications it is desirable to operate over a fairly wide bandwidth which requires a low mechanical Q. Achievement of a low Q and high efficiency at the same time requires careful design and an optimization of the electroacoustic properties of the known transducer materials. Evidently, different types of transducing mechanisms may be superior for specific uses.

Types of Transducers

Some of the types of transducers used in the early days of sonar have now become nearly obsolete (underwater bells, carbon microphones, electrodynamic Fessenden oscillators, quartz crystal units, etc.). Several other types have found only limited application in sonar up to the present time (electrostatic or capacitor microphones, electrical discharges, explosives, mechanical noise makers, etc.) Thus, we shall here confine ourselves to a short discussion of the most common types of transducers used in modern sonar equipments. They are: (1) magnetostrictive (2) electromagnetic or variable reluctance (3) piezoelectric (4) ferroelectric and (5) electrostrictive.

Magnetostrictive Transducers

Almost all ferromagnetic materials show some magnetostrictive activity. For example, nickel contracts whereas iron and cobalt expand in the direction of the applied magnetic field. Nickel, iron, cobalt and their alloys have sufficiently large magnetostriction to be utilized in sonar transducers. Magnetostrictive ferrites show promise in sonar but as yet are still in the experimental stage as transducer materials. Since magnetostrictive materials will change their dimensions in a definite direction for any applied static magnetic field independent of its polarity, an applied AC field will cause a contraction or expansion of twice the input frequency.

This frequency doubling can be avoided by superimposing the AC signal upon a steady magnetic biasing field which prestretches or precontracts the material. Such a bias field can be supplied by a direct current through a transducer winding, by means of a permanent magnet placed in the magnetic circuit, or by magnetic remanence flux within the material itself.

Magnetostrictive transducers have the advantages of being exceptionally rugged, trouble free and capable of withstanding extreme temperatures and shocks without damage. Being metallic and therefore good heat conductors, they can dissipate large amounts of heat which can easily be removed during high power use. Their impedance can be conveniently adjusted by changing the number of turns in the winding. They are capable of good efficiency as sound generators over a frequency range of about 5–50 kc. As receiving devices or hydrophones they are useful down to a few hundred cycles per second.

Electromagnetic Transducers

Electromagnetic, or, as they are now being more commonly called variable reluctance transducers are used to generate low frequency sound waves in water. These consist essentially of an electromagnet with an air gap. The movable portion of the core is attached to a diaphragm, or piston, which is coupled to the water. A polarizing flux is required to avoid frequency doubling as in the magnetostrictive units. The variable reluctance operation results in considerable non-linearity as well

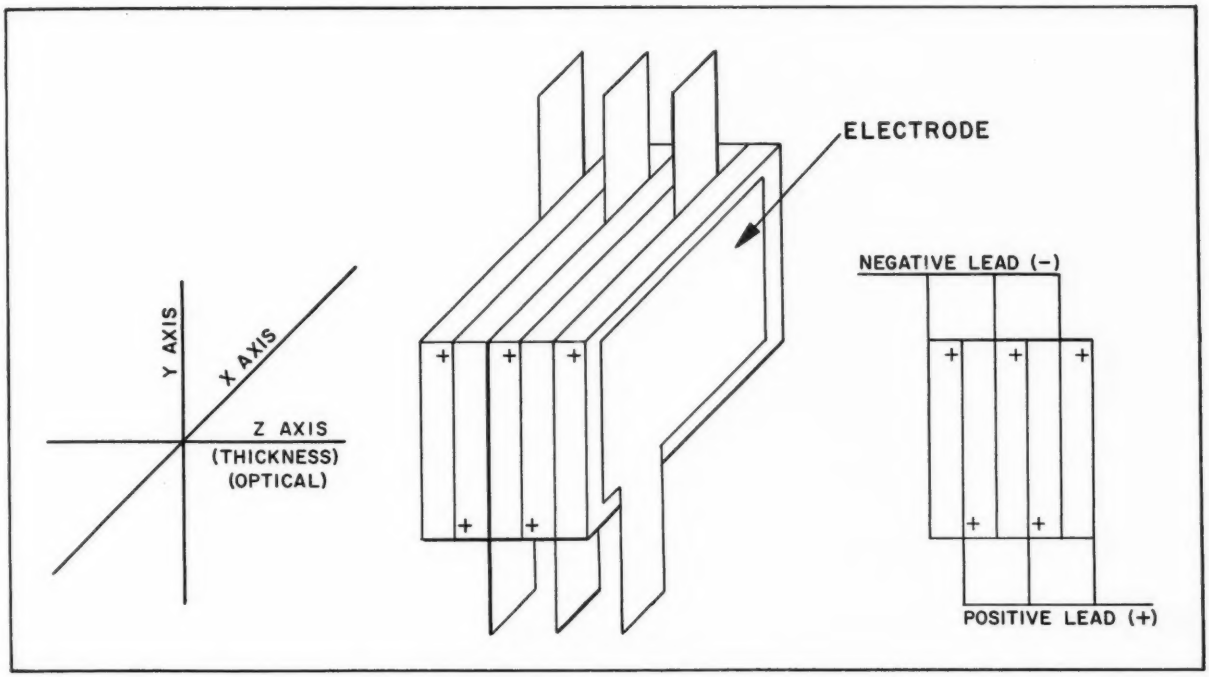


Figure 1

as dependence of performance on hydrostatic pressure. The impedance varies significantly with level so that the characteristics of a given transducer as a receiver depart from those for high level transmission.

The electromagnetic transducers have the advantage of being naturally suited to the production of high acoustic energy in the frequency range below about 2 kc. They can easily be built to have total efficiencies greater than 50%. Narrow bandwidth is an inherent characteristic of most such sonar transducers.

Piezoelectric Transducers

Piezoelectricity is that property of certain crystalline materials which causes them to produce a charge when subjected to a mechanical deformation. Conversely, an applied electrical field produces a mechanical stress. The most commonly used piezoelectric material in modern sonar is ammonium dihydrogen phosphate (ADP), a synthetic crystal. Piezoelectric crystals do not require external polarization since the local fields associated with their molecular structure provide a built-in bias. Figure 1 shows a typical ammonium dihydrogen phosphate crystal with its electrodes. An axis of symmetry exists normal to the axis through its electrodes (optical axis) so that when a voltage is applied across the electrodes a slight structural reorientation occurs, producing changes of the crystal dimensions along the length and width. It is these two dimensions which are usually designed (by themselves, or together with loading masses) to be part of the mechanically resonant system.

A disadvantage of ADP is the cost involved in growing large crystals (greater than about a 3 in. cube). It is generally used in naval sonar equipments at frequencies of 10 kc and above. Its low dielectric constant (about 14) makes it a high impedance material.

Ferroelectric Transducers

Ferroelectricity is similar to piezoelectricity and the two are often lumped together as being part of the piezoelectric group.* There are distinct differences, however, in the properties of ADP and a ferroelectric such as Rochelle salt which is still used in sonar applications because of its great sensitivity (unmatched by any other known material). Rochelle salt, like ADP, does not require any added polarization to enhance its electroacoustic characteristics. Unlike ADP, the performance of Rochelle salt is voltage dependent and limited by hysteresis losses. It is the similarity of its hysteresis effects to the ferromagnetics which has caused the effect to be referred to as ferroelectricity.

Rochelle salt has as its main advantage a remarkably high electroacoustic activity which permits efficient operation over a wide frequency band. It is a low impedance material (dielectric constant greater than 1000).

*For details of the differences, see W. G. Cady, *Piezoelectricity* (McGraw-Hill, New York, 1946).

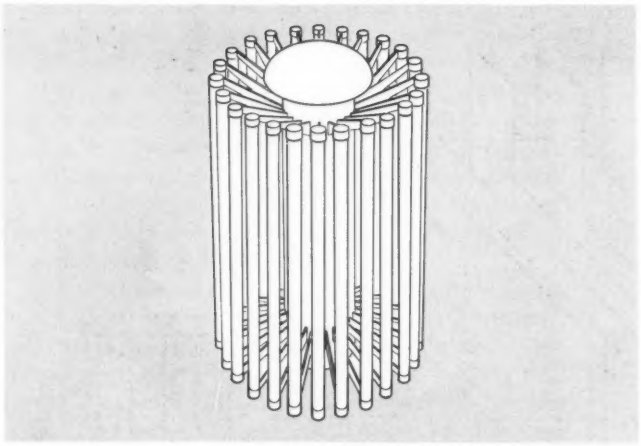


Figure 2

Electrostrictive Transducers

There is a growing family of sonar transducers using the electrostrictive effect which, again, resembles the behavior of piezoelectric and ferroelectric materials. Basically, electrostriction is a second order piezoelectric effect and is particularly strong in the barium and zirconium titanate ceramic materials. Like the magnetostrictive materials, the dimension change is independent of the polarity of the applied electric field. To avoid frequency doubling and enhance activity the electrostrictive materials are used in a remanent polarized condition such as the remanent magnetization state often used with magnetostrictive transducers.

Advantages of the electrostrictive ceramics include the ease of fabrication by conventional ceramic methods into a variety of extremely useful shapes (cylinders, plates, spheres, etc.). They are relatively low in cost (compared to ADP or nickel), can be cemented into large pieces for low frequency, or high power applications. They are low impedance materials, permitting low voltage fields even at very high power input levels. Whereas thin ceramic discs are being used at frequencies as high as several megacycles, cylindrical elements of several inches diameter have been built with resonances below 10 kc.

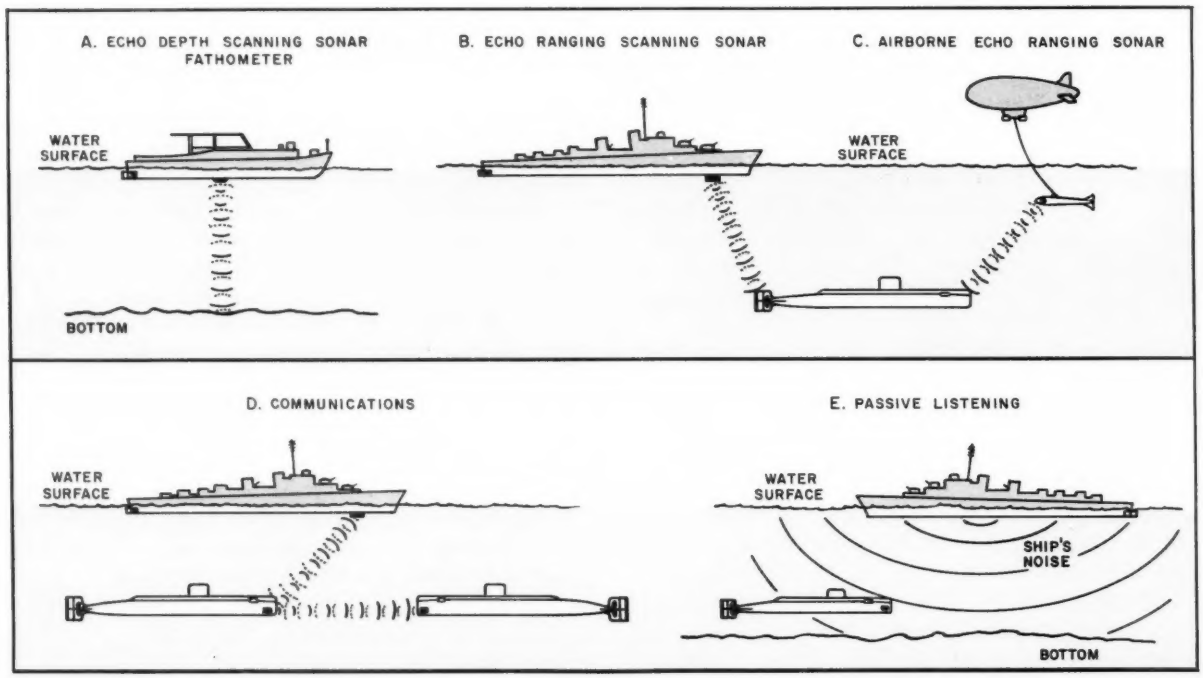


Figure 3

Sonar Transducer Applications

The various types of sonar systems can usually be divided into three basic classifications — passive, echo ranging and communications. In passive listening any sonic signal or noise emitted by a target and reaching the hydrophone (underwater microphone) or array of hydrophones is detected and amplified before being presented to the operator. The limitations imposed on this type of system will be the magnitude of the received signal compared to the magnitude of the sea noise and the ship's own noise. Directional information can be obtained, for example, by using an array of line hydrophones such as those shown in Figure 2. By using groups of hydrophones within the array, and controlling the phase delay in the circuits connecting them, beam patterns can be formed in the plane of the array. By switching methods the beams can be steered electrically. Directivity in a plane perpendicular to the plane of the array is usually made by making the transducers several wavelengths long. Arrays of this type could be mounted on a submarine or in a shore installation, or could be lowered from a hovering aircraft. The transducers are designed to be able to listen to a wide band of audible frequencies. This type of listening would be used to detect submarines, surface ships and the cavitation noise of moving torpedoes. Although only bearing information can be obtained by passive listening, the advantage of this technique is that the presence of the listening vessel or installation is not disclosed to the enemy.

To detect quiet targets echo ranging systems are used which include a signal generator and a transmitting transducer by which the energy developed is converted to an acoustic signal in the water. A small portion of the energy reaching the target is returned to either the transmitting transducer now in the role of a listening device, or a separate hydrophone. By the use of short bursts of energy both range and bearing information can be determined from the direction of the received echo and the time required for the transmitted signal to return as an echo. The speed of a moving target can be determined by observing any difference between the frequency of the emitted and received pulses (Doppler effect). By observing the quality of the received pulse a trained sonar operator can tell much about the type of target.

By mounting a transducer assembly in the nose of a torpedo we are able to make use of sonar techniques using either passive or echo ranging systems. The acoustic torpedo using a passive sonar system converts the acoustic energy detected by the listening hydrophones to electrical form for the steering controls, and is thereby directed toward the cavitation noises of the target's propellers. More reliable acoustic torpedoes do not rely on the target's own noise for steering. Short bursts of ultrasonic energy from the transducer are reflected back by the target and supply the necessary steering information to the torpedo. The torpedo using an echo ranging system cannot be "fooled" by many of the noise makers used as countermeasures or "foiled" by submarines running deep where propeller cavitation may be nonexistent.

The measurement of depth of the sea by the echo ranging technique is perhaps the most important nonmilitary application. An underwater reversible transducer is mounted flush with a ship's hull. A pulse of energy of a few milliseconds duration is sent out and reflected by the ocean floor. The received signal is amplified and fed to a recorder. One method of recording depth is to start the pen moving across the chart each time a sound pulse is emitted until the received signal makes a dot on the chart; the distance from the base line to the dot is proportional to the depth. In this manner a continuous record is obtained. Depths from 10 to several thousand feet may be recorded. Typical transducer applications are shown in Figure 3. This scheme may be used as a navigational aid if the vessel is in waters where the depths are charted. With higher frequencies and larger transducer faces this type of equipment can be used to locate large schools of fish and shrimp beds.

Finally, underwater object locaters and swimmers' communications systems are a valuable aid in underwater salvaging and exploring. The weight range, from small, portable acoustic flashlights for swimmers to large shipborne transducer arrays is of the order of 10^3. The range of frequencies covered by the devices described above is about 10^1. This is indicative of the wide variety of problems in design, measurements and choices of materials that are facing our transducer engineers. We have gone a long way from the device invented by Leonardo da Vinci for underwater listening — a long hollow tube held with one end in the water and the other end at the ear. A significant portion of this progress can be ascribed to the activities of Raytheon's Sonar Department and its predecessor, the old Submarine Signal Company.

ENGINEERING SEMINARS

The series of engineering seminars which was begun last year will reconvene about the first of November. The time and place of the first talk will be announced through established channels.

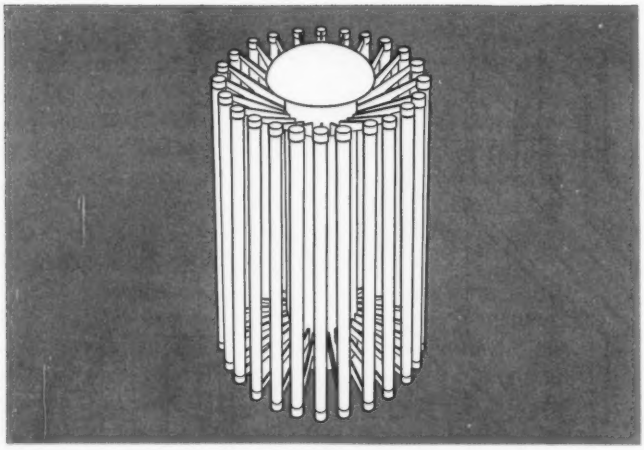


Figure 2

Electrostrictive Transducers

There is a growing family of sonar transducers using the electrostrictive effect which, again, resembles the behavior of piezoelectric and ferroelectric materials. Basically, electrostriction is a second order piezoelectric effect and is particularly strong in the barium and zirconium titanate ceramic materials. Like the magnetostrictive materials, the dimension change is independent of the polarity of the applied electric field. To avoid frequency doubling and enhance activity the electrostrictive materials are used in a remanent polarized condition such as the remanent magnetization state often used with magnetostrictive transducers.

Advantages of the electrostrictive ceramics include the ease of fabrication by conventional ceramic methods into a variety of extremely useful shapes (cylinders, plates, spheres, etc.). They are relatively low in cost (compared to ADP or nickel), can be cemented into large pieces for low frequency, or high power applications. They are low impedance materials, permitting low voltage fields even at very high power input levels. Whereas thin ceramic discs are being used at frequencies as high as several megacycles, cylindrical elements of several inches diameter have been built with resonances below 10 kc.

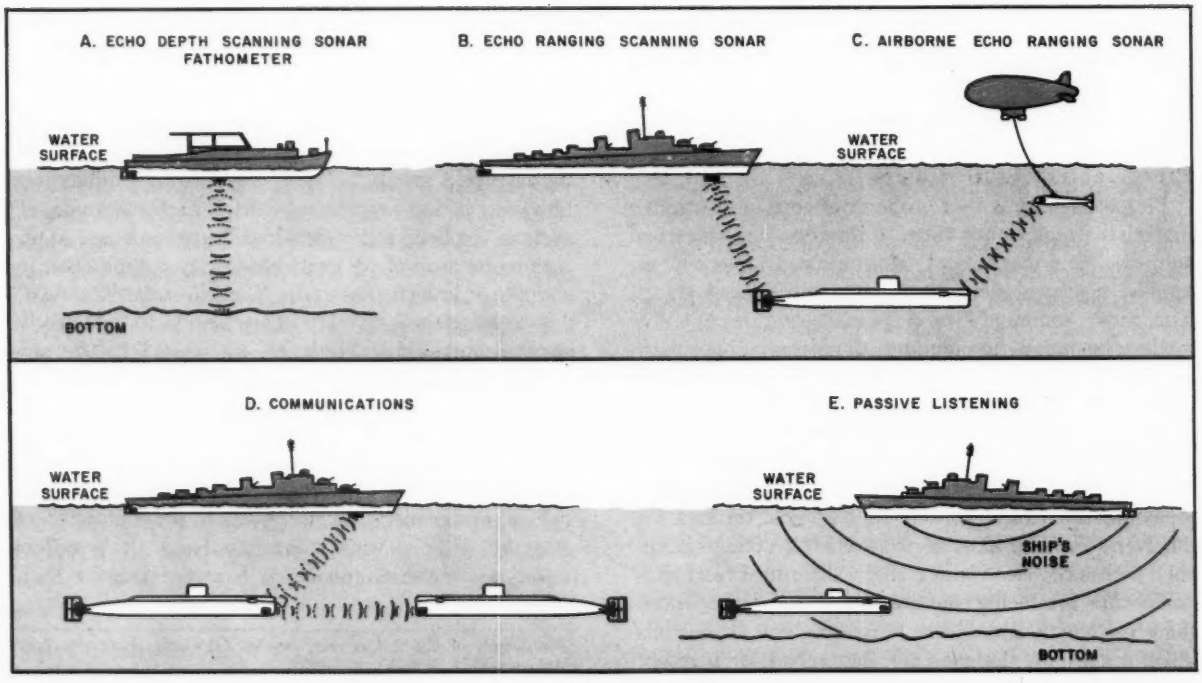


Figure 3

Sonar Transducer Applications

The various types of sonar systems can usually be divided into three basic classifications — passive, echo ranging and communications. In passive listening any sonic signal or noise emitted by a target and reaching the hydrophone (underwater microphone) or array of hydrophones is detected and amplified before being presented to the operator. The limitations imposed on this type of system will be the magnitude of the received signal compared to the magnitude of the sea noise and the ship's own noise. Directional information can be obtained, for example, by using an array of line hydrophones such as those shown in Figure 2. By using groups of hydrophones within the array, and controlling the phase delay in the circuits connecting them, beam patterns can be formed in the plane of the array. By switching methods the beams can be steered electrically. Directivity in a plane perpendicular to the plane of the array is usually made by making the transducers several wavelengths long. Arrays of this type could be mounted on a submarine or in a shore installation, or could be lowered from a hovering aircraft. The transducers are designed to be able to listen to a wide band of audible frequencies. This type of listening would be used to detect submarines, surface ships and the cavitation noise of moving torpedoes. Although only bearing information can be obtained by passive listening, the advantage of this technique is that the presence of the listening vessel or installation is not disclosed to the enemy.

To detect quiet targets echo ranging systems are used which include a signal generator and a transmitting transducer by which the energy developed is converted to an acoustic signal in the water. A small portion of the energy reaching the target is returned to either the transmitting transducer now in the role of a listening device, or a separate hydrophone. By the use of short bursts of energy both range and bearing information can be determined from the direction of the received echo and the time required for the transmitted signal to return as an echo. The speed of a moving target can be determined by observing any difference between the frequency of the emitted and received pulses (Doppler effect). By observing the quality of the received pulse a trained sonar operator can tell much about the type of target.

By mounting a transducer assembly in the nose of a torpedo we are able to make use of sonar techniques using either passive or echo ranging systems. The acoustic torpedo using a passive sonar system converts the acoustic energy detected by the listening hydrophones to electrical form for the steering controls, and is thereby directed toward the cavitation noises of the target's propellers. More reliable acoustic torpedoes do not rely on the target's own noise for steering. Short bursts of ultrasonic energy from the transducer are reflected back by the target and supply the necessary steering information to the torpedo. The torpedo using an echo ranging system cannot be "fooled" by many of the noise makers used as countermeasures or "foiled" by submarines running deep where propeller cavitation may be nonexistent.

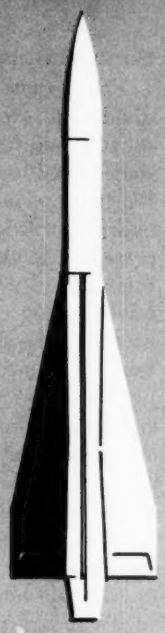
The measurement of depth of the sea by the echo ranging technique is perhaps the most important nonmilitary application. An underwater reversible transducer is mounted flush with a ship's hull. A pulse of energy of a few milliseconds duration is sent out and reflected by the ocean floor. The received signal is amplified and fed to a recorder. One method of recording depth is to start the pen moving across the chart each time a sound pulse is emitted until the received signal makes a dot on the chart; the distance from the base line to the dot is proportional to the depth. In this manner a continuous record is obtained. Depths from 10 to several thousand feet may be recorded. Typical transducer applications are shown in Figure 3. This scheme may be used as a navigational aid if the vessel is in waters where the depths are charted. With higher frequencies and larger transducer faces this type of equipment can be used to locate large schools of fish and shrimp beds.

Finally, underwater object locaters and swimmers' communications systems are a valuable aid in underwater salvaging and exploring. The weight range, from small, portable acoustic flashlights for swimmers to large shipborne transducer arrays is of the order of 10^3. The range of frequencies covered by the devices described above is about 10^1. This is indicative of the wide variety of problems in design, measurements and choices of materials that are facing our transducer engineers. We have gone a long way from the device invented by Leonardo da Vinci for underwater listening — a long hollow tube held with one end in the water and the other end at the ear. A significant portion of this progress can be ascribed to the activities of Raytheon's Sonar Department and its predecessor, the old Submarine Signal Company.

ENGINEERING SEMINARS

The series of engineering seminars which was begun last year will reconvene about the first of November. The time and place of the first talk will be announced through established channels.

GUIDED MISSILE RADOMES



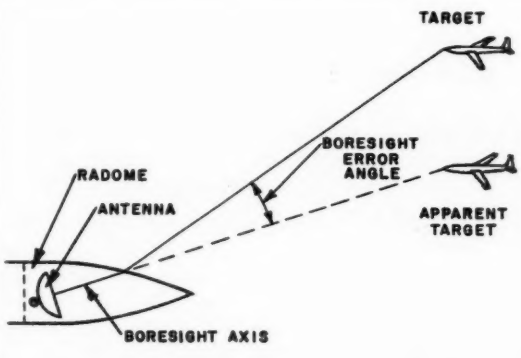
F. R. Youngren
Bedford Laboratory

A missile which homes on radar energy reflected from a target must have a radar receiver aboard. The usual method for collecting the reflected energy is to use a paraboloidal antenna or dish mounted in the missile's nose. Because it is desirable to protect this dish from the air flow generated by the missile's flight through the atmosphere, a windshield covering over the dish is needed. This covering is called a radome.

A successful radome must satisfy a number of requirements which often conflict. In brief, it must have satisfactory electrical properties (to allow the radar energy to pass with minimum distortions and loss); it must be shaped so that its drag is minimized (so as not to reduce the missile's range); and it must be structurally capable of withstanding the loads imposed on it by the air it is crashing through at supersonic speed. In order to better understand the limitations imposed by these requirements, and their areas of conflict, we shall examine them in more detail.

The radome is an electromagnetic window on the front of the missile. Its function is to transmit the radar waves without loss and without distortion. A loss in energy (due either to absorption within the dielectric material of the radome, or due to reflection from the surface of the radome) will reduce the range at which the missile can detect the target. Fortunately, it is not very difficult to obtain good transmission; this is accomplished by choosing low-loss materials and by choosing a wall thickness such that reflections are minimized.

A second electrical requirement which the radome must meet is that it must not distort the radar waves by bending or refracting them. If the radome bends the rays of energy coming from the target, then the target will appear to be displaced from its true position by an angle which is called the radome's boresight error angle (see Figure 1). This angle is usually not zero and usually it changes in magnitude and sign depending on which region of the radome is between the missile seeker dish and the target. One might think that it is necessary to keep the error angle small; this



GEOMETRY OF BORESIGHT ERROR ANGLE

Figure 1

is not so, since with a homing missile the miss distance in feet due to the error angle (which is less than a degree at the most) is continuously reduced as the missile approaches the target, until at intercept it becomes negligible. The parameter which, of necessity, must be kept small is the angular rate of change of error angle over the radome. This requirement is imposed by the navigational system used to steer the missile to an interception with the target. The system responds to apparent target angular movement rates with respect to the missile. Thus a changing radome error adding to a target angular movement will either seem to speed up the angular rate (tending to make the missile nervous, resulting in oscillation) or else slow it down (tending to make the missile sluggish and slow to respond). Both effects result in increased miss distances and can become serious enough to cause the missile to become wildly unstable.

The simple way out of this trouble is to mount and rotate the dish about the center of a hemispherical radome. Because of symmetry, this shape does not change the apparent position of the target. It is too blunt, however, and thus generates too much drag for use on the nose of a missile unless no other solution can be found.

The aerodynamicist would prefer to use a long pointed shape for the nose of the missile (see Figure 2). These shapes generate less drag because they turn the

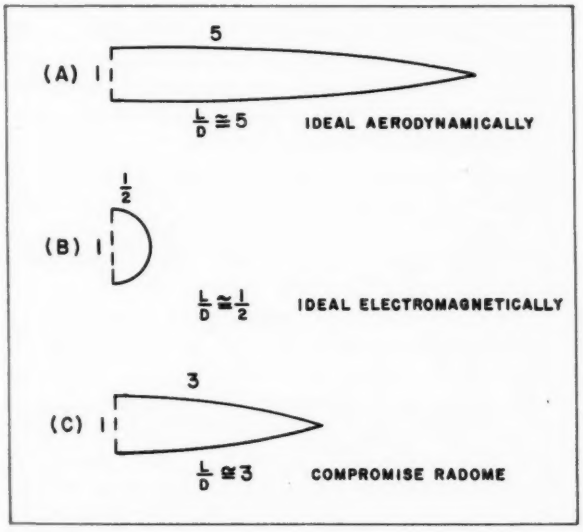


Figure 2

air through a smaller angle (the pressure increment on the nose tip is roughly proportional to the 3/2 power of the nose cone angle). Because the aerodynamicist is also interested in flight range, weight is important. This consideration would limit the radome length even if no other consideration were present, for as the radome grows longer, it also grows heavier. Eventually, the range decrement due to increasing weight balances the increment due to decreasing drag, and at this point the radome length gives maximum flight range. This occurs at a length-to-diameter ratio of from three to five, the exact number depending on the drag of the rest of the missile. Note that the electrically optimum hemisphere has a length-to-diameter ratio of 1/2.

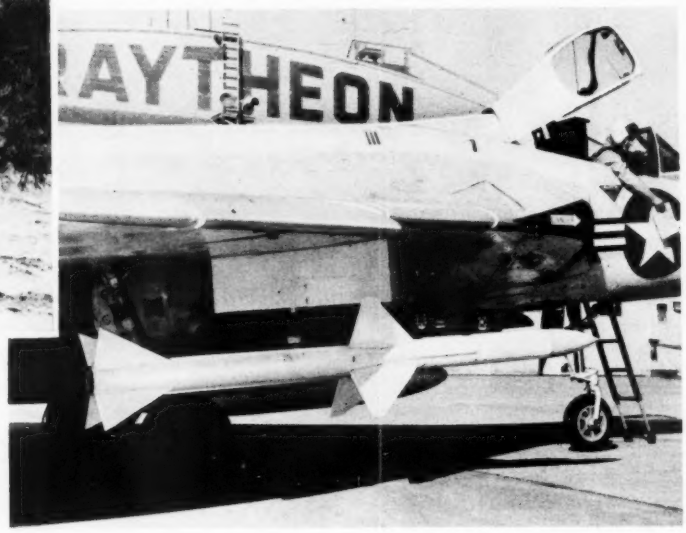
Since the radome forms the contour of the missile nose, it is subjected to structural loading from the pressures of the air. This loading is of two types, a compression along the radome length due to the drag force, and a bending load which occurs whenever the missile nose is inclined at an angle to the flight direction. The radome structure is a thin-walled shell, devoid of metal bracing, struts, or ribs because they would interfere with the electrical requirements. The structure is usually a doubly curved wall and for this reason compression is quite difficult to analyze. Because of geometry, however, the maximum bending moment occurs at the joint to the rest of the missile; analysis is usually confined to checking the integrity of this joint.

A problem which is still not completely understood, and the subject for much current research, is the effect of rain erosion on radomes. At modern missile speeds the water droplets in rain hit the surface of the radome like bullets. Impact pressures can become high enough to fracture many materials, an effect which is further increased by surface imperfections. Only the hardest of metals and ceramics can escape damage from high speed rain impact. Experimental studies have shown that the erosion rate is proportional to a high power of the component of the impact velocity normal to the radome surface. For this reason sharply pointed radomes with surfaces whose inclination to the airstream is small are preferred. Note that shapes whose aerodynamic drag is small tend to be of this type.

High speed flight also poses another radome design problem: aerodynamic heating. The air on the surface of the missile is heated because it has been brought to rest (with respect to the missile), thus converting into heat its high kinetic energy from the missile's flight velocity. This heat soaks into the radome and the rest of the missile's structure. In general, this heating causes a weakening of structural properties; in addition, thermal gradients in the structure cause thermal stresses. Some radome materials have been known to fracture under the thermal stresses imposed by the rapid heating which occurs in a missile flight.

Salt encrustation on radomes used by the Navy is another problem facing the radome designer. This has the effect of increasing the wall thickness and thereby de-tuning the radome from optimum electrical performance.

Moisture absorbed into the wall has a somewhat similar effect in that it increases the dielectric constant



of the material of the wall. This makes the wall appear to be electrically thicker and de-tunes the radome from optimum electrical performance. It is interesting to note, however, that radomes which were manufactured slightly too thin can be improved somewhat when they are loaded with absorbed moisture.

Radomes have been made from a great number of materials; however, the materials usually fall into two general classes — plastics and ceramics. A property that all radome materials have in common is low electrical transmission loss.

Most of the current missile radomes are fabricated of glass-reinforced plastics, usually a fiberglass cloth laminated with a plastic resin. This method of construction produces a tough, machinable, dimensionally stable material well suited for use as a radome. The chief restriction on its use comes from the limited ability of plastics to withstand high temperatures.

As missile flight speeds have increased, the need for materials with better properties than plastics at high temperatures has become more acute. The class of materials which can supply acceptable high temperature properties are the ceramics. In addition, they have low electrical loss and resist rain erosion due to their hardness. This hardness, however, causes difficulties in machining or grinding these materials to shape. In order to overcome these difficulties, the emphasis today is being placed on moulding ceramic radomes to the final desired shape and thickness.

All of the aforementioned effects have been considered in the design of the radomes for the two current Raytheon missiles, Sparrow III and Hawk. Both use pointed nose shapes to minimize drag and rain erosion; these shapes represent a compromise between the blunt nose desired by the electrical designer and the long pointed nose desired by the aerodynamicist. Both radomes are of fiberglass cloth laminated with a high-temperature-resistant plastic resin, carefully machined to precise thickness distributions whose tapers are designed to achieve the desired electrical characteristics. In many ways these radomes are like lenses whose geometrical precision has a controlling effect on the system accuracy.

The future poses many challenges for the radome designer. Flight speeds are becoming so high that the air next to the radome is partially ionized due to the intense aerodynamic heating. Perhaps the radome designer can overcome this by cooling the boundary layer air or by somehow compensating for effects resulting from this ionization. The high temperatures impose further problems on radome materials, both with regard to strength and to electrical properties. The next generation of missiles will be larger, increasing the problems of fabrication. The bending stresses in the radome wall are also increased for these large radomes, because the wall thickness is designed to be tuned to the radar wavelength and therefore must be held constant. The net result of these uncertainties is that it is difficult to scale from a workable present model to a future which is virtually unexplored.

Co-operative Education at Raytheon

R. E. Mudgett
Personnel Relations

Introduction

When primeval man taught his offspring methods of survival against the forces of nature, he (presumably without knowing it) utilized a form of co-operative education. It is unlikely his contemporary animals realized they were "co-operating" by matching their physical and mental powers with those of man. Moreover, man was undoubtedly ungracious enough not to appreciate this "co-operation," particularly when running at top speed hotly pursued at an increasingly decreasing distance by, for instance, a snarling, snapping, saber-toothed tiger. While this form of education somehow fell short of perfection, its overall effectiveness is indicated by man's continued survival and by his apparent prosperity and progress.

During the past few thousand years, co-operative education has appeared in many forms of apprenticeship — to craftsmen, professionals and scholars. Teacher and employer were often one and the same person. Medical schools have long worked closely with hospitals to provide clinical observation and experience for embryonic physicians and surgeons and neophyte lawyers have traditionally "clerked" with experienced members of the bar before advancing to full professional status.

It is perhaps surprising then that in 1903 friends and associates of the late Dean (then Professor) Herman W. Schneider of the University of Cincinnati greeted his proposal for an integrated work-study program in engineering with friendly but unconcealed skepticism. By 1906, however, he had gained support from a large number of local manufacturers and finally "persuaded" the faculty at Cincinnati to try his plan. One of the strongest factors in acceptance of this idea was recognition by a growing number of industrial leaders in the United States of the lack of practical knowledge among engineering graduates who were coming to them for employment. Dean Schneider had in addition carefully studied case records of Lehigh University graduates and found that most of those who had shown marked engineering ability soon after completing college courses had worked during vacations, worked while attending college or stayed out of college for a while to earn enough money to continue their education.

During the next ten years Cincinnati was joined by six other colleges and universities, until today there are more than 35 accredited degree-granting colleges and universities offering technical and nontechnical co-operative programs.

World War II brought a substantial decline in co-operative enrollments because of the urgent demand for accelerated programs. In the initial post-war expansion Raytheon placed its first co-op from Northeastern University in the Specifications Department section of Microwave and Power Tube Operations (December, 1946). During the next several years only a few co-ops were added. With the growing shortage of engineers and scientists, particularly during and after the "Korean Conflict," Microwave and Power Tube's acceptance of co-ops rapidly spread to other Divisions. There are today nearly 200 co-ops majoring in engineering and the physical sciences employed in Raytheon's Massachusetts plants and laboratories. Schools represented are: Antioch, Detroit, Drexel, M.I.T., Northeastern and R.P.I.

Checking experimental equipment in a bell jar.

These pictures show cooperative students engaged in various activities in Raytheon Laboratories.

Objectives and Nature of the Program

Fundamental values of co-operative education may well be illustrated by the following statements of Raytheon policy regarding co-op students:

"Co-operative education implies the establishment of a program between a college and company directed toward the training of students in industrial jobs related *to the academic program provided by the college."*

This statement underscores the so-called "triangular" relationship among participants: college, employer and student, and points up the raison d'être for any co-op plan — the provision of an integrated work-study program through a job related to the student's academic major.

Raytheon assignments range functionally from research through manufacturing and are in no way artificially synthesized. They are actual jobs which would require additional full-time employees if co-ops were not employed.

Assignments should vary in complexity with the ability, academic background and prior experience of each individual student, depending, of course, on available work. In time-sequence, work experience should progress from initial routine assignments through increasingly complex subprofessional duties during undergraduate years to professional level assignments at or near graduation.

For example, in the Microwave and Power Tube Division the co-op's first assignment would probably be in the drafting department while later assignments might follow in standards, production and applications groups. His last few assignments would likely find him as an assistant to a tube development project engineer. This rotational program has obvious merit in providing a well-rounded engineering background. A corollary advantage is the exposure of the student to a diverse group of engineering functions which help him determine his career interests more precisely, even if only through the "process of elimination."

Progression is also provided within a single technical group in many parts of the Company. Here the student begins with routine duties in collecting data, simple computation. testing and breadboarding and gradually moves through limited design problems toward professional level design work.

While the following descriptions of specific assignments are oversimplified and necessarily limited in length, they nevertheless suggest the breadth and depth of work actually performed by Raytheon co-ops:

Ran magnetron acceptance tests, updated status records and tube frequency graphs, prepared testing and aging schedules.

Studying the grain structure of a metal specimen.

Measured magnetic properties including impedance, B-H curves and hysteresis losses for various metals for the evaluation of magnetostrictive properties for transducer applications.

Polished specimens for metallurgical inspection and ran experimental cooling curves for tin-titanium mixtures.

Modified test equipment and wrote test procedures for incoming inspection.

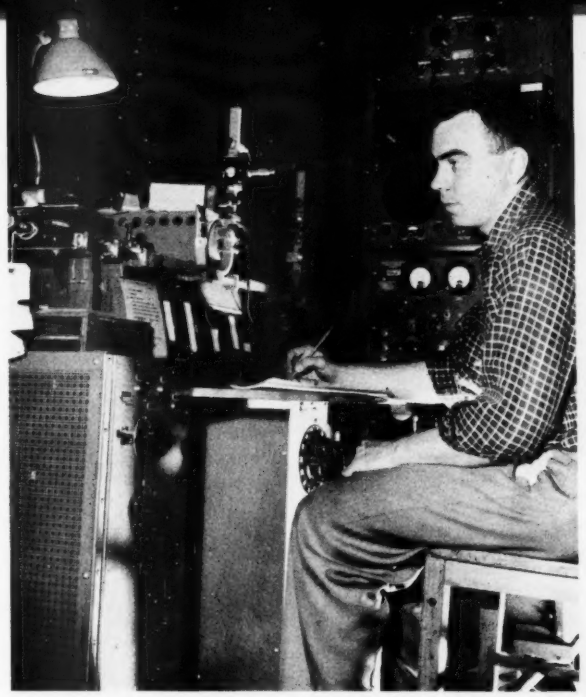
Set up equations for aerodynamic performance calculations on I.B.M., plotted wind tunnel test data and reduced rocket engine data to graphic form.

Designed a highly-filtered, 1% voltage regulation power supply for a countermeasures system.

"It is the task of both college and company to plan and execute a program which fulfills the objectives of the program and at the same time results in material advantages to the company."

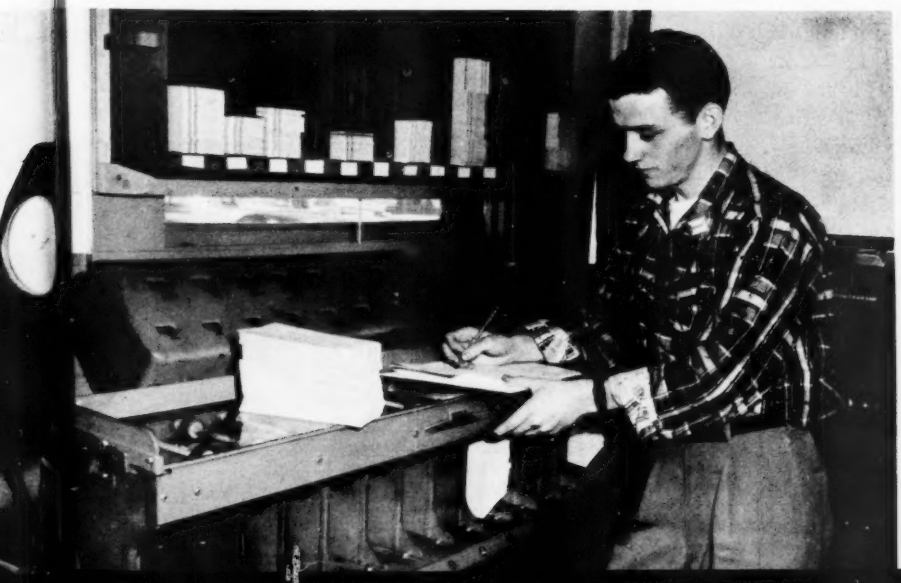
Since the objectives of participants are to realize the benefits of the co-operative plan, a summation of the advantages to each, student and company, should also describe the program's objectives. It should be emphasized, however, that the key objective of any co-op plan is an integrated work-study program related to the student's academic major. The advantages herein cited are more completely summarized in Henry Armsby's *Cooperative Education in the United States* (published by the U. S. Department of Health, Education and Welfare, Office of Education) and represent current thinking on the subject.

The student, through related work experience, is better able to evaluate his career interests and decide on a suitable type of work; at the same time, he is learning practical applications of theories studied in college. He is helped through industrial discipline to form good work habits and to acquire a feeling of self-reliance and a sense of responsibility. His first-hand contact with other employees and with problems of labor management increase the co-op's understanding of the human factors in industry. Finally, he has an opportunity for partial and perhaps even total self-support and often receives a higher salary upon graduation than the "regular" student.



Checking the performance of an experimental magnetron.

The company is able to train carefully selected technical employees in company organization and procedures during the regular educational process, without having to maintain a separate training school. A natural by-product of the exchange of ideas among students,



Running a statistical analysis for quality determination.

Checking experimental equipment in a bell jar.

These pictures show cooperative students engaged in various activities in Raytheon Laboratories.

Objectives and Nature of the Program

Fundamental values of co-operative education may well be illustrated by the following statements of Raytheon policy regarding co-op students:

"Co-operative education implies the establishment of a program between a college and company directed toward the training of students in industrial jobs related *to the academic program provided by the college."*

This statement underscores the so-called "triangular" relationship among participants: college, employer and student, and points up the raison d'être for any co-op plan — the provision of an integrated work-study program through a job related to the student's academic major.

Raytheon assignments range functionally from research through manufacturing and are in no way artificially synthesized. They are actual jobs which would require additional full-time employees if co-ops were not employed.

Assignments should vary in complexity with the ability, academic background and prior experience of each individual student, depending, of course, on available work. In time-sequence, work experience should progress from initial routine assignments through increasingly complex subprofessional duties during undergraduate years to professional level assignments at or near graduation.

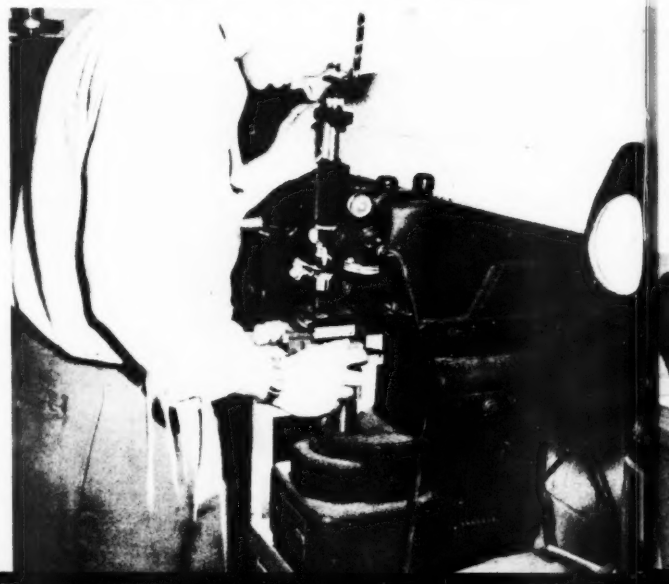
For example, in the Microwave and Power Tube Division the co-op's first assignment would probably be in the drafting department while later assignments might follow in standards, production and applications groups. His last few assignments would likely find him as an assistant to a tube development project engineer. This rotational program has obvious merit in providing a well-rounded engineering background. A corollary advantage is the exposure of the student to a diverse group of engineering functions which help him determine his career interests more precisely, even if only through the "process of elimination."

Progression is also provided within a single technical group in many parts of the Company. Here the student begins with routine duties in collecting data, simple computation, testing and breadboarding and gradually moves through limited design problems toward professional level design work.

While the following descriptions of specific assignments are oversimplified and necessarily limited in length, they nevertheless suggest the breadth and depth of work actually performed by Raytheon co-ops:

Ran magnetron acceptance tests, updated status records and tube frequency graphs, prepared testing and aging schedules.

Studying the grain structure of a metal specimen.



Measured magnetic properties including impedance, B-H curves and hysteresis losses for various metals for the evaluation of magnetostrictive properties for transducer applications.

Polished specimens for metallurgical inspection and ran experimental cooling curves for tin-titanium mixtures.

Modified test equipment and wrote test procedures for incoming inspection.

Set up equations for aerodynamic performance calculations on I.B.M., plotted wind tunnel test data and reduced rocket engine data to graphic form.

Designed a highly-filtered, 1% voltage regulation power supply for a countermeasures system.

"It is the task of both college and company to plan and execute a program which fulfills the objectives of the program and at the same time results in material advantages to the company."

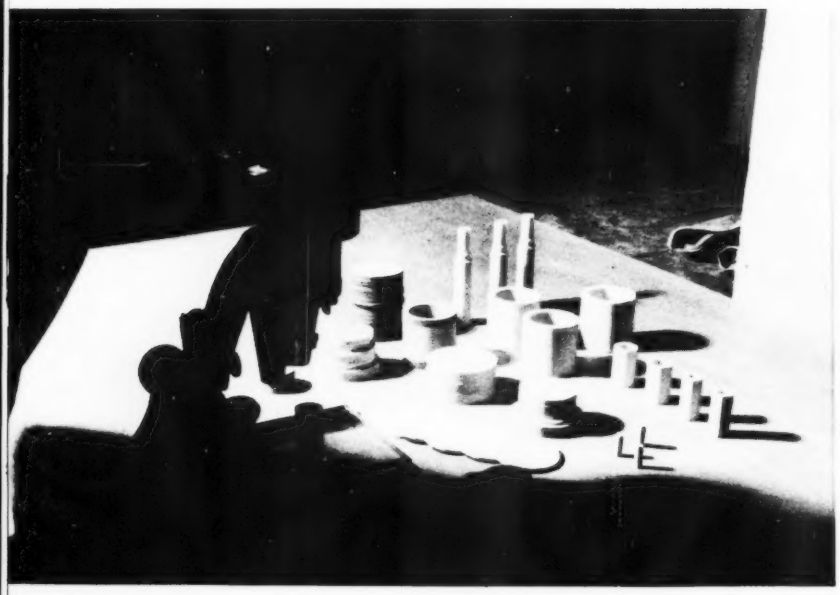
Since the objectives of participants are to realize the benefits of the co-operative plan, a summation of the advantages to each, student and company, should also describe the program's objectives. It should be emphasized, however, that the key objective of any co-op plan is an integrated work-study program related to the student's academic major. The advantages herein cited are more completely summarized in Henry Armsby's *Cooperative Education in the United States* (published by the U. S. Department of Health, Education and Welfare, Office of Education) and represent current thinking on the subject.

The student, through related work experience, is better able to evaluate his career interests and decide on a suitable type of work; at the same time, he is learning practical applications of theories studied in college. He is helped through industrial discipline to form good work habits and to acquire a feeling of self-reliance and a sense of responsibility. His first-hand contact with other employees and with problems of labor management increase the co-op's understanding of the human factors in industry. Finally, he has an opportunity for partial and perhaps even total self-support and often receives a higher salary upon graduation than the "regular" student.

Checking the performance of an experimental magnetron.

The company is able to train carefully selected technical employees in company organization and procedures during the regular educational process, without having to maintain a separate training school. A natural by-product of the exchange of ideas among students,

Running a statistical analysis for quality determination.



A cooperative student in electrical engineering analyzes structural variations in ceramic parts.

supervisors and school co-ordinators leads to the university becoming more interested in industry's problems and often results in its becoming a basic research center for these problems. A particularly significant benefit to co-operating companies is after-graduation retention of co-ops as full-time employees. While neither a company nor a student has any written or implied contractual obligation relative to permanent employment, experience at M.I.T. and Northeastern shows that from 30 to 50 per cent of their co-ops remain with co-op employers after graduation. Raytheon's retention rate appears to be somewhat higher than average for these two schools. While in 1957 the two schools' overall average retention was about 30 per cent, more than 50 per cent of Raytheon's graduating co-ops remained with the company.

Advantages to the college are equally important. Integration of work and study inherently fosters an up-to-date practical educational program. As a direct result, much descriptive technical matter can be eliminated from courses, allowing correspondingly greater emphasis to be placed on fundamental principles. Then too, the alternating periods between shop or laboratory and classroom permit fuller scheduling of university faculty and plant with the possibility of many more students being accommodated.

There are, of course, disadvantages to such a program. While most schools try to provide year-round job coverage by grouping students in alternate divisions, it is sometimes difficult to match backgrounds and abilities of alternating students on the same job. At times alternates have not even been available, resulting in imbalance of both effectiveness and continuity. A co-op program requires a highly skilled effort, especially on the supervisor's part, to solve these special problems in scheduling and training.

"*The advantages accruing to the Company can be realized only through careful planning and administration of this program.*"

Existing policy provides for general management of co-operative engineering and science programs by the Vice President, Engineering and Research and overall co-ordination by the Professional Personnel Section of the Personnel Relations Department (referral of qualified applicants to appropriate Divisions, plants and laboratories, interviewing, scheduling, counselling, policy review, etc.). Co-ordination at plant levels is provided by local administrators who determine job openings and give day-to-day guidance to supervisors and students.

The schools provide co-ordination through a department of co-ordination or perhaps some individual faculty member, depending on the size of the school and its method of operation. It is the co-ordinator's job to evaluate, place, counsel and guide students within the framework of the particular school's policy.

Perhaps the single most important person in administration of the work portion of the program is the co-op's direct supervisor. The supervisor assesses the

co-op's abilities and gears the assignment accordingly. He is obviously closer to the co-op during his work than other administrators of either school or company and has by far the greatest opportunity to direct and motivate the student's work.

Through the use of rating sheets required by the schools, the supervisor evaluates each work period's performance in terms of specific factors such as technical ability, effectiveness, industry, judgment, group adaptability, etc. Most ratings provide space for comments and a description of work performed. These ratings are extremely important and become part of the student's record. Ratings should be carefully considered and thoroughly discussed with the student before his return to school for maximum effectiveness. It should be remembered that "gentle treatment" is frequently not a kind action.

Conclusion

That co-ops are of more initial value to Raytheon after graduation than the typical graduating senior seems axiomatic since they not only have genuine related work experience but some realization of the differences between theory and practice. Moreover, having worked for several years they have a much wider knowledge of company and plant procedures than a graduate without such experience.

Through annual work reports to his school, the student consolidates his experiences and can creatively analyze technical problems within his grasp. One such student submitted his annual work report in an IRE student paper competition and was awarded first place at local, state and regional levels.

A place for the co-op program in Raytheon's future plans seems assured. While during the last ten years the program has grown tremendously in numbers to keep pace with Raytheon's total growth, it is doubtful that the future will see much of an increase in numbers of students unless the supply of students admitted to co-op institutions increases far more sharply than expected. Therefore, greatest gains can probably be made in more effective utilization of students, particularly through concentration on higher admission standards and on raising the nature and level of co-op assignments to keep pace with increased competition for college admission over the next several years.

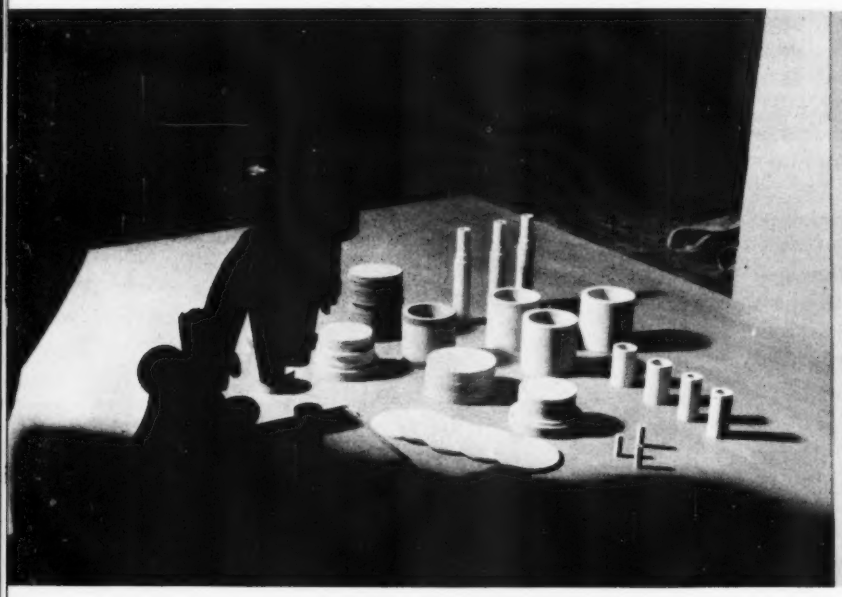
A brochure, "Co-op Engineering Experience with Education," published jointly by co-op students at Cornell, M.I.T. and R.P.I. aptly quotes for the basic philosophy of co-operative education Sir Francis Bacon who, during the 17th century, said:

"*. . . Crafty men condemn studies, simple men admire them, and wise men use them, for they teach not their own use; but that is a wisdom without them and above them, won by observation . . .*"

The word "observation," which in today's literal sense, implies detachment from that being observed, might well be replaced by "experience" to express the essence of co-operative education since the student observes through the eyes of actual job performance.

Publications & Papers

A. E. Bryson and G. A. Ouellette	"Optimum Paths to the Moon and the Planets"
L. S. Greenberg and R. C. Wonson	"The Clarification of the Capacity Problems in High Frequency Transistors"
O. J. Guentert and R. L. Mozzi	"The Monoclinic Modification of Gadolinium Sesquioxide Gd_2O_3"
J. M. Lavine	"An AC Apparatus for Measuring the Ordinary Hall Coefficient of Ferromagnetic Metals and Semiconductors"
J. A. Mullen	"Measurements of the Harmonic Output of an S-Band BWO"
R. Reichel	"Weight Estimating Problems of Airborne Electronics Equipment"
D. Root	"An Analysis of Diode Characteristics with Application of Inversion Layer Theory to Forward Bias Conditions"
E. Schloemann	"Ferrimagnetic Resonance in the Compensation Region"
E. Schloemann	"Ferromagnetic Resonance in Polycrystalline Ferrites with Large Anisotropy II, Hexagonal Materials with a Preferential Plane"
M. H. Sirvetz	"Development of a High Power L-Band Isolator"
H. Statz, R. Pucel and C. Lanza	"Semiconductor Devices Utilizing the Interaction of Electrons and Holes in Space-Charge Regions"
R. S. Wagner	"Production of Dislocations in Germanium by Thermal Shock"
S. P. Wolsky	"Germanium and Silicon Surfaces"



A cooperative student in electrical engineering analyzes structural variations in ceramic parts.

supervisors and school co-ordinators leads to the university becoming more interested in industry's problems and often results in its becoming a basic research center for these problems. A particularly significant benefit to co-operating companies is after-graduation retention of co-ops as full-time employees. While neither a company nor a student has any written or implied contractual obligation relative to permanent employment, experience at M.I.T. and Northeastern shows that from 30 to 50 per cent of their co-ops remain with co-op employers after graduation. Raytheon's retention rate appears to be somewhat higher than average for these two schools. While in 1957 the two schools' overall average retention was about 30 per cent, more than 50 per cent of Raytheon's graduating co-ops remained with the company.

Advantages to the college are equally important. Integration of work and study inherently fosters an up-to-date practical educational program. As a direct result, much descriptive technical matter can be eliminated from courses, allowing correspondingly greater emphasis to be placed on fundamental principles. Then too, the alternating periods between shop or laboratory and classroom permit fuller scheduling of university faculty and plant with the possibility of many more students being accommodated.

There are, of course, disadvantages to such a program. While most schools try to provide year-round job coverage by grouping students in alternate divisions, it is sometimes difficult to match backgrounds and abilities of alternating students on the same job. At times alternates have not even been available, resulting in imbalance of both effectiveness and continuity. A co-op program requires a highly skilled effort, especially on the supervisor's part, to solve these special problems in scheduling and training.

"The advantages accruing to the Company can be realized only through careful planning and administration of this program."

Existing policy provides for general management of co-operative engineering and science programs by the Vice President, Engineering and Research and overall co-ordination by the Professional Personnel Section of the Personnel Relations Department (referral of qualified applicants to appropriate Divisions, plants and laboratories, interviewing, scheduling, counselling, policy review, etc.). Co-ordination at plant levels is provided by local administrators who determine job openings and give day-to-day guidance to supervisors and students.

The schools provide co-ordination through a department of co-ordination or perhaps some individual faculty member, depending on the size of the school and its method of operation. It is the co-ordinator's job to evaluate, place, counsel and guide students within the framework of the particular school's policy.

Perhaps the single most important person in administration of the work portion of the program is the co-op's direct supervisor. The supervisor assesses the

co-op's abilities and gears the assignment accordingly. He is obviously closer to the co-op during his work than other administrators of either school or company and has by far the greatest opportunity to direct and motivate the student's work.

Through the use of rating sheets required by the schools, the supervisor evaluates each work period's performance in terms of specific factors such as technical ability, effectiveness, industry, judgment, group adaptability, etc. Most ratings provide space for comments and a description of work performed. These ratings are extremely important and become part of the student's record. Ratings should be carefully considered and thoroughly discussed with the student before his return to school for maximum effectiveness. It should be remembered that "gentle treatment" is frequently not a kind action.

Conclusion

That co-ops are of more initial value to Raytheon after graduation than the typical graduating senior seems axiomatic since they not only have genuine related work experience but some realization of the differences between theory and practice. Moreover, having worked for several years they have a much wider knowledge of company and plant procedures than a graduate without such experience.

Through annual work reports to his school, the student consolidates his experiences and can creatively analyze technical problems within his grasp. One such student submitted his annual work report in an IRE student paper competition and was awarded first place at local, state and regional levels.

A place for the co-op program in Raytheon's future plans seems assured. While during the last ten years the program has grown tremendously in numbers to keep pace with Raytheon's total growth, it is doubtful that the future will see much of an increase in numbers of students unless the supply of students admitted to co-op institutions increases far more sharply than expected. Therefore, greatest gains can probably be made in more effective utilization of students, particularly through concentration on higher admission standards and on raising the nature and level of co-op assignments to keep pace with increased competition for college admission over the next several years.

A brochure, "Co-op Engineering Experience with Education," published jointly by co-op students at Cornell, M.I.T. and R.P.I. aptly quotes for the basic philosophy of co-operative education Sir Francis Bacon who, during the 17th century, said:

". . . Crafty men condemn studies, simple men admire them, and wise men use them, for they teach not their own use; but that is a wisdom without them and above them, won by observation . . ."

The word "observation," which in today's literal sense, implies detachment from that being observed, might well be replaced by "experience" to express the essence of co-operative education since the student observes through the eyes of actual job performance.

Publications & Papers

A. E. Bryson and G. A. Ouellette	"Optimum Paths to the Moon and the Planets"
L. S. Greenberg and R. C. Wonson	"The Clarification of the Capacity Problems in High Frequency Transistors"
O. J. Guentert and R. L. Mozzi	"The Monoclinic Modification of Gadolinium Sesquioxide Gd_2O_3"
J. M. Lavine	"An AC Apparatus for Measuring the Ordinary Hall Coefficient of Ferromagnetic Metals and Semiconductors"
J. A. Mullen	"Measurements of the Harmonic Output of an S-Band BWO"
R. Reichel	"Weight Estimating Problems of Airborne Electronics Equipment"
D. Root	"An Analysis of Diode Characteristics with Application of Inversion Layer Theory to Forward Bias Conditions"
E. Schloemann	"Ferrimagnetic Resonance in the Compensation Region"
E. Schloemann	"Ferromagnetic Resonance in Polycrystalline Ferrites with Large Anisotropy II, Hexagonal Materials with a Preferential Plane"
M. H. Sirvetz	"Development of a High Power L-Band Isolator"
H. Statz, R. Pucel and C. Lanza	"Semiconductor Devices Utilizing the Interaction of Electrons and Holes in Space-Charge Regions"
R. S. Wagner	"Production of Dislocations in Germanium by Thermal Shock"
S. P. Wolsky	"Germanium and Silicon Surfaces"

DESIGN CONSIDERATIONS on Transistor High Frequency Amplifiers

R. Martinengo
Semiconductor Division

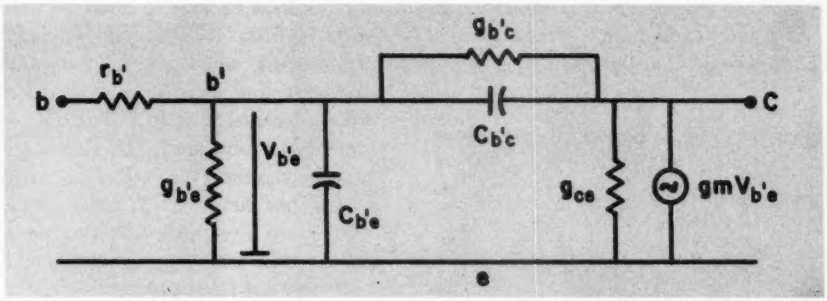
While the most publicized use of transistors has been in portable and auto radio receivers, there has been a widespread swing to transistors in numerous other applications, the most important of which is probably the computer field. With the availability of high frequency transistors capable of operation at 100 megacycles, transistors will increasingly be designed into such diverse applications as television receivers and satellite instrumentation. It is the purpose of this article, therefore, to acquaint the reader with the basic facts concerning the behavior of transistors at high frequencies.

It is common knowledge that transistor gain decreases with frequency; for a common base configuration the collector-to-emitter current ratio, alpha, decreases with frequency, and at a frequency commonly defined as alpha cut-off frequency ($f_{\alpha b}$), the magnitude of alpha is 0.707 of its low frequency value, with a corresponding phase shift of 57°. For a typical audio transistor the $f_{\alpha b}$ may be from a few hundred kilocycles to one or two megacycles; high frequency transistors take over at two or three megacycles; fusion alloy types are available with $f_{\alpha b}$ up to 20 megacycles; surface barrier and diffused base types commercially available extend the range to over 100 megacycles. It would not be rash to say that this frequency limit will be pushed higher and higher by new devices which are now in the developmental stage.

An insight into the behavior of transistors at high frequencies may be obtained from the high frequency equivalent circuit of Table I for common emitter operation.

This circuit is particularly useful because the parameters involved are relatively independent of frequency in the useful frequency spectrum, so that the response of a transistor may be fairly well calculated if the equivalent circuit parameters are known. Table I gives typical values for these parameters along with several formulas which are useful in determining high frequency characteristics. Inspection of the circuit discloses that the output current will decrease with frequency, since it is proportional to $V_{b'e}$ which is the internal base-to-emitter voltage and not the external applied voltage. It is seen that the combination of $r_{b'}$, $g_{b'e}$, and $C_{b'e}$ forms a low pass filter which effectively limits the high frequency response of the transistor. In fact, the alpha cut-off frequency is equal to $(1/2\pi\, C_{b'e}\, r_e)$; r_e enters into the formula because $f_{\alpha b}$ pertains to common base operation. The analagous relation for common emitter operation is $f_{\alpha e} = g_{b'e}/2\pi\, C_{b'e} = (1 - \alpha_o)f_{\alpha b}$. Most data sheets list $f_{\alpha b}$ rather than $f_{\alpha e}$ since $f_{\alpha b}$ indicates more explicitly the useful operating range of a transistor. For example, a transistor with an $f_{\alpha b}$ of 20 megacycles and a current gain h_{fe} of 100 will have an $f_{\alpha e}$ of approximately $f_{\alpha b}/h_{fe}$ or 0.2 megacycles; yet it still has gain well beyond this frequency, since h_{fe} drops off at approximately 6 decibels per octave. Quite a few manufacturers list a figure of merit such as F_{max} which is the maximum frequency of oscillation and the frequency at which power gain is equal to unity [equation (f)]. Knowing F_{max}, it is possible to predict the gain vs frequency characteristic within a few decibels. Thus, for a typical 2N417 transistor with $f_{\alpha b} = 20$ mc, $C_{b'c} = 12\ \mu\mu f$ and $r_{b'} = 100$ ohms, F_{max} is equal to 25.9 megacycles; maximum available gain in an unilateralized circuit increases about 6 decibels per octave as shown in Figure 1.

TABLE I



High frequency hybrid circuit

Typical values (for alloy junction rf transistor with 5 mc $f_{\alpha b}$)

$r_{b'}$	100 ohms
$g_{b'e}$	0.5 millimho
$C_{b'e}$	1000 $\mu\mu$f
$C_{b'c}$	12 $\mu\mu$f
g_{ce}	0.2 micromho
gm	35 millimhos

(a) $$g_{b'e} = \frac{1-\alpha_o}{r_e} = \frac{qIe}{kT}(1-\alpha_o)$$

(b) $$r_e = \frac{kT}{qIe} = \frac{26}{Ie\ ma} = \frac{1-\alpha_o}{g_{b'e}}$$

(c) $$C_{b'e} = \frac{1}{2\pi r_e f_{\alpha b}} = \frac{g_{b'e}}{2\pi f_{\alpha e}}$$

(d) $$gm = \frac{\alpha_o qIe}{kT} = \frac{\alpha_o}{r_e}$$

$$f_{\alpha e} = (1-\alpha_o) f_{\alpha b}$$

(e) Maximum power gain

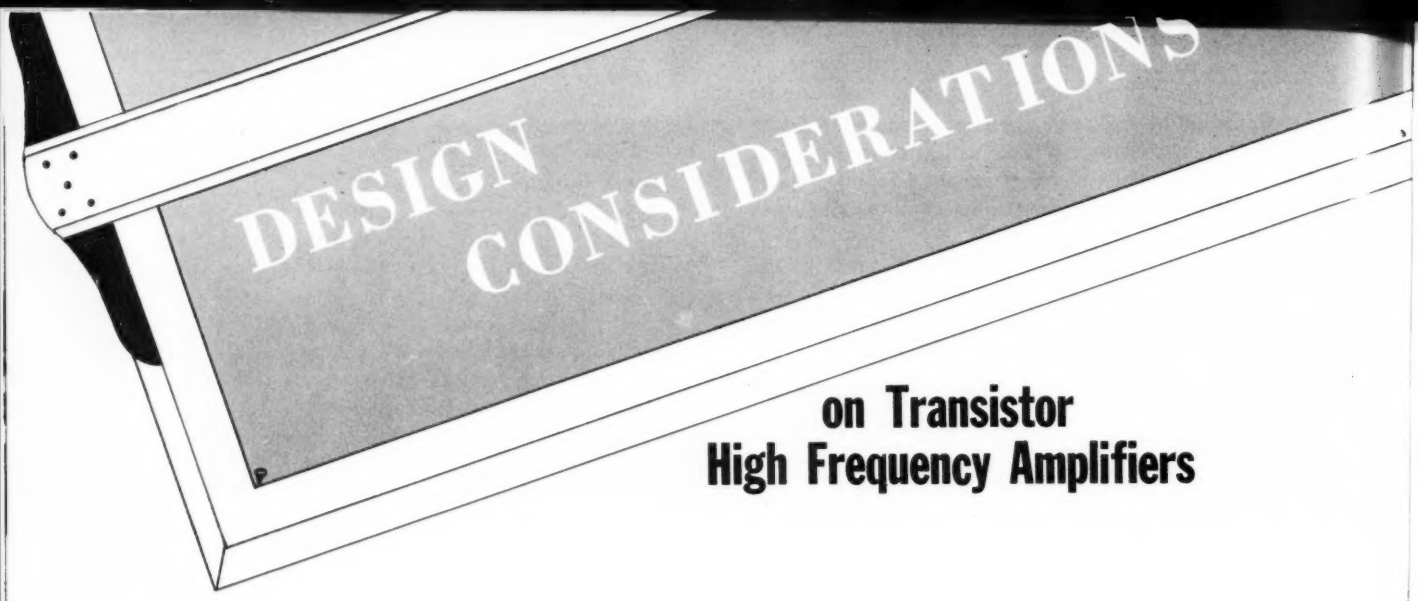
$$MPG = \frac{gm}{4\omega^2 r_{b'} C_{b'c} C_{b'e}} = \frac{\alpha_o f_{\alpha b}}{8\pi f^2 r_{b'} C_{b'e}}$$

(f) Maximum Frequency of Oscillation

$$F_{max} = \frac{\alpha_o f_{\alpha b}}{8\pi r_{b'} C_{b'c}} = \frac{1}{4\pi}\sqrt{\frac{gm}{r_{b'} C_{b'c} C_{b'e}}}$$

Explanation of Symbols

α_o = Low frequency collector-to-emitter current ratio with collector short-circuited
$r_{b'}$ = Extrinsic base resistance due to resistivity of material between base contact and active transistor region
$g_{b'e}$ = forward-biased emitter conductance
$C_{b'e}$ = diffusion capacitance
$C_{b'c}$ = collector-base depletion layer capacitance
$g_{b'c}$, g_{ce} = leakage conductances
gm = intrinsic transconductance
q = electron charge
k = Boltzmann's constant
T = absolute temperature
$f_{\alpha b}$, $f_{\alpha e}$ = frequency at which short circuit current ratio is 0.707 of its low frequency value. $f_{\alpha b}$ is common base, $f_{\alpha e}$ common emitter.



on Transistor High Frequency Amplifiers

R. Martinengo
Semiconductor Division

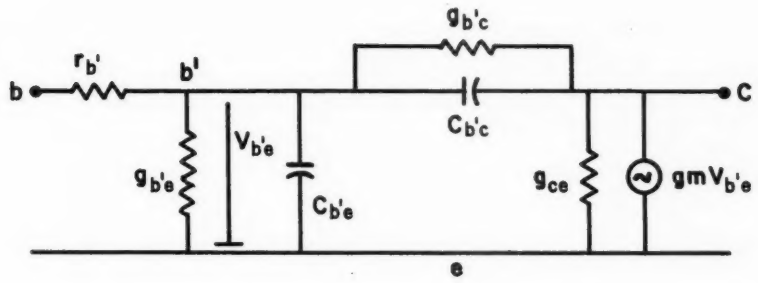
While the most publicized use of transistors has been in portable and auto radio receivers, there has been a widespread swing to transistors in numerous other applications, the most important of which is probably the computer field. With the availability of high frequency transistors capable of operation at 100 megacycles, transistors will increasingly be designed into such diverse applications as television receivers and satellite instrumentation. It is the purpose of this article, therefore, to acquaint the reader with the basic facts concerning the behavior of transistors at high frequencies.

It is common knowledge that transistor gain decreases with frequency; for a common base configuration the collector-to-emitter current ratio, alpha, decreases with frequency, and at a frequency commonly defined as alpha cut-off frequency ($f_{\alpha b}$), the magnitude of alpha is 0.707 of its low frequency value, with a corresponding phase shift of 57°. For a typical audio transistor the $f_{\alpha b}$ may be from a few hundred kilocycles to one or two megacycles; high frequency transistors take over at two or three megacycles; fusion alloy types are available with $f_{\alpha b}$ up to 20 megacycles; surface barrier and diffused base types commercially available extend the range to over 100 megacycles. It would not be rash to say that this frequency limit will be pushed higher and higher by new devices which are now in the developmental stage.

An insight into the behavior of transistors at high frequencies may be obtained from the high frequency equivalent circuit of Table I for common emitter operation.

This circuit is particularly useful because the parameters involved are relatively independent of frequency in the useful frequency spectrum, so that the response of a transistor may be fairly well calculated if the equivalent circuit parameters are known. Table I gives typical values for these parameters along with several formulas which are useful in determining high frequency characteristics. Inspection of the circuit discloses that the output current will decrease with frequency, since it is proportional to $V_{b'e}$ which is the internal base-to-emitter voltage and not the external applied voltage. It is seen that the combination of $r_{b'}$, $g_{b'e}$, and $C_{b'e}$ forms a low pass filter which effectively limits the high frequency response of the transistor. In fact, the alpha cut-off frequency is equal to $(1/2\pi\, C_{b'e}\, r_e)$; r_e enters into the formula because $f_{\alpha b}$ pertains to common base operation. The analagous relation for common emitter operation is $f_{\alpha e} = g_{b'e}/2\pi\, C_{b'e} = (1 - \alpha_o)f_{\alpha b}$. Most data sheets list $f_{\alpha b}$ rather than $f_{\alpha e}$ since $f_{\alpha b}$ indicates more explicitly the useful operating range of a transistor. For example, a transistor with an $f_{\alpha b}$ of 20 megacycles and a current gain h_{fe} of 100 will have an $f_{\alpha e}$ of approximately $f_{\alpha b}/h_{fe}$ or 0.2 megacycles; yet it still has gain well beyond this frequency, since h_{fe} drops off at approximately 6 decibels per octave. Quite a few manufacturers list a figure of merit such as F_{max} which is the maximum frequency of oscillation and the frequency at which power gain is equal to unity [equation (f)]. Knowing F_{max}, it is possible to predict the gain vs frequency characteristic within a few decibels. Thus, for a typical 2N417 transistor with $f_{\alpha b} = 20$ mc, $C_{b'c} = 12$ $\mu\mu$f and $r_{b'} = 100$ ohms, F_{max} is equal to 25.9 megacycles; maximum available gain in an unilateralized circuit increases about 6 decibels per octave as shown in Figure 1.

TABLE I



High frequency hybrid circuit

Typical values (for alloy junction rf transistor with 5 mc $f_{\alpha b}$)

$r_{b'}$	100 ohms
$g_{b'e}$	0.5 millimho
$C_{b'e}$	1000 $\mu\mu$f
$C_{b'c}$	12 $\mu\mu$f
g_{ce}	0.2 micromho
gm	35 millimhos

(a) $$g_{b'e} = \frac{1-\alpha_o}{r_e} = \frac{qIe}{kT}(1-\alpha_o)$$

(b) $$r_e = \frac{kT}{qIe} = \frac{26}{Ie\ ma} = \frac{1-\alpha_o}{g_{b'e}}$$

(c) $$C_{b'e} = \frac{1}{2\pi r_e f_{\alpha b}} = \frac{g_{b'e}}{2\pi f_{\alpha e}}$$

(d) $$gm = \frac{\alpha_o qIe}{kT} = \frac{\alpha_o}{r_e}$$

$$f_{\alpha e} = (1-\alpha_o) f_{\alpha b}$$

(e) Maximum power gain

$$MPG = \frac{gm}{4\omega^2 r_{b'} C_{b'c} C_{b'e}} = \frac{\alpha_o f_{\alpha b}}{8\pi f^2 r_{b'} C_{b'e}}$$

(f) Maximum Frequency of Oscillation

$$F_{max} = \frac{\alpha_o f_{\alpha b}}{8\pi r_{b'} C_{b'c}} = \frac{1}{4\pi}\sqrt{\frac{gm}{r_{b'} C_{b'c} C_{b'e}}}$$

Explanation of Symbols

α_o = Low frequency collector-to-emitter current ratio with collector short-circuited
$r_{b'}$ = Extrinsic base resistance due to resistivity of material between base contact and active transistor region
$g_{b'e}$ = forward-biased emitter conductance
$C_{b'e}$ = diffusion capacitance
$C_{b'c}$ = collector-base depletion layer capacitance
$g_{b'c}$, g_{ce} = leakage conductances
gm = intrinsic transconductance
q = electron charge
k = Boltzmann's constant
T = absolute temperature
$f_{\alpha b}$, $f_{\alpha e}$ = frequency at which short circuit current ratio is 0.707 of its low frequency value. $f_{\alpha b}$ is common base, $f_{\alpha e}$ common emitter.

The complete curve may be constructed by calculating the low frequency maximum power gain which is approximately 1/(4 hib hob); for the 2N417, taken as an example, the low frequency maximum power gain is 41 decibels. This is shown in Figure 1 also.

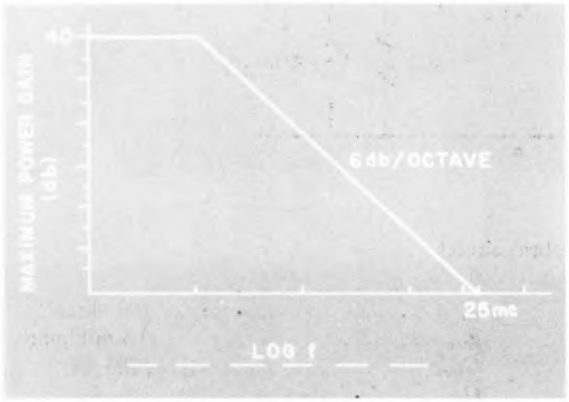


Figure 1

RF and IF Amplifiers

Transistor RF amplifiers are quite different in nature than RF amplifiers using tubes; the input and ouput impedances are much lower, and since the transistor is essentially a power amplifying device, matching is required for maximum gain. There is also an internal feedback path through $C_{b'c}$ which must be neutralized if regenerative effects are to be avoided. A typical circuit for an IF amplifier is shown in Figure 2. Cn is the neutralizing capacitor; its value depends on the turns ratio involved. It may also go from secondary winding to the base if the proper phasing is observed. This type of neutralization results in a neutralized amplifier, rather than a unilateralized one. It uses only capacitive feedback, whereas in order to obtain a unilateral amplifier, a resistance must be used either in series or parallel with Cn. The reason may be seen in the equivalent circuit, where a small conductance exists between collector and base terminals. For lower frequencies this difference is generally negligible and will not affect the results obtained; for higher frequencies a resistor may be required for proper operation.

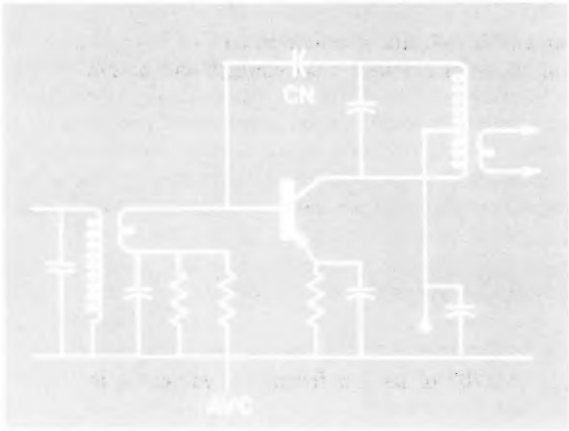


Figure 2

Another factor which must be taken into consideration when designing IF amplifiers for production is the normal variation in collector capacity, which may vary ± 2 $\mu\mu$f for a nominal 12 $\mu\mu$f unit. This variation, coupled with the variation in the neutralizing capacitor within its tolerance, would result in varying degrees of skewing of the bandpass characteristic, and, for extreme cases, might cause oscillation to occur. To account for the variations a deliberate mismatch of input and output impedances is achieved with a consequent loss in gain. In general, the loss in gain will be determined by the degree of skew which can be tolerated and by the deviation of collector capacity from its nominal value; the tighter the limits, the more nearly the useful gain will approach the maximum available gain.

Automatic gain control may be achieved through control of emitter current, base current, or collector voltage; emitter current control is most widely used since collector voltage control also affects collector capacity and thus causes detuning effects; control of base current is more critical of transistor parameters and may be affected by interchanging transistors. Typical variation of gain with emitter current is shown in Figure 3. Along with the variation in gain, the input and output impedances increase, causing the overall bandwidth to narrow.

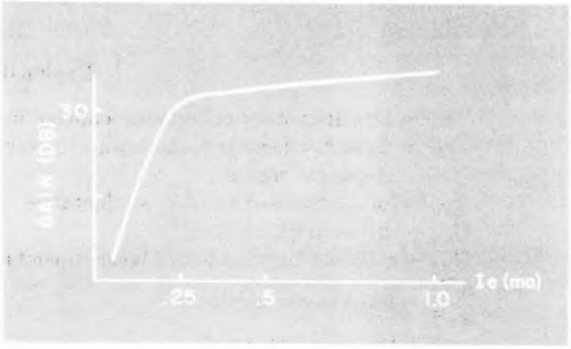


Figure 3

Wide Band Amplifiers

Techniques used in transistor wide band amplifiers are similar to those used in vacuum tube circuits. A useful figure of merit which may be used to determine

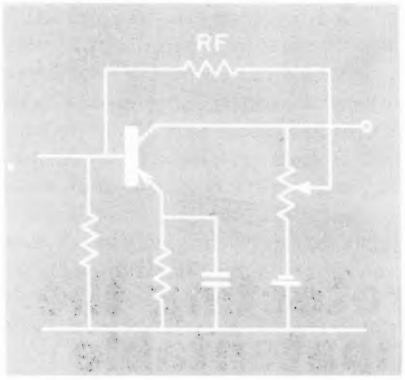


Figure 4

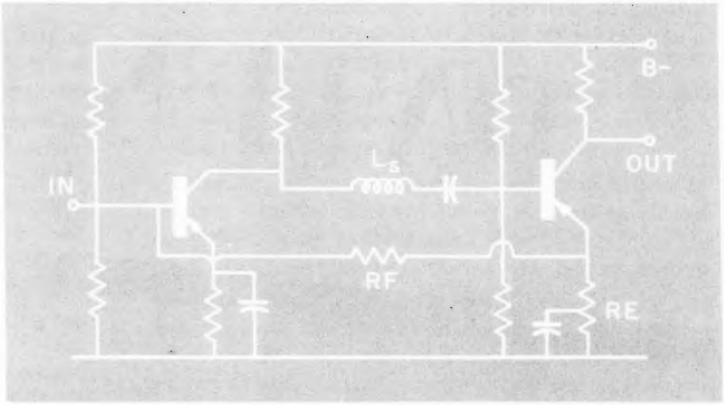


Figure 5

the approximate gain is VG·BW = $\alpha_o f_{\alpha b}$ where VG and BW are single-stage voltage gain and bandwidth, respectively. Negative feedback may be applied from collector to base in a one-stage common emitter amplifier, as shown in Figure 4. A very stable two-stage circuit is shown in Figure 5. Feedback from second emitter to first base reduces the overall gain; the series inductance between collector and base extends the frequency response without affecting the gain. Typical results obtained using this circuit with two 2N417's for different bandwidths are shown in Figure 6; input and output impedances were 1000 ohms so that iterative operation of a number of stages is possible.

Most computer applications involve non-linear use of transistors in switching and pulse circuits. The response time of a pulse amplifier is primarily a function of the alpha cut-off frequency. Typical rise time for a Raytheon 2N428 with a 200 ohm load in a common emitter circuit is 0.4 microseconds. Rise time may be reduced by increasing the base driving input pulse. However, this method also increases the storage time, which is the time between the end of the input pulse and the knee of the transistor output pulse.

Storage time is due to an excess of minority carriers stored in the base region; a reduction of storage time may be obtained by maintaining a steady reverse bias at the base. Another method of reducing rise time without seriously affecting storage time involves the use of a speed-up capacitor of a few hundred $\mu\mu$f placed across the series base input resistor.

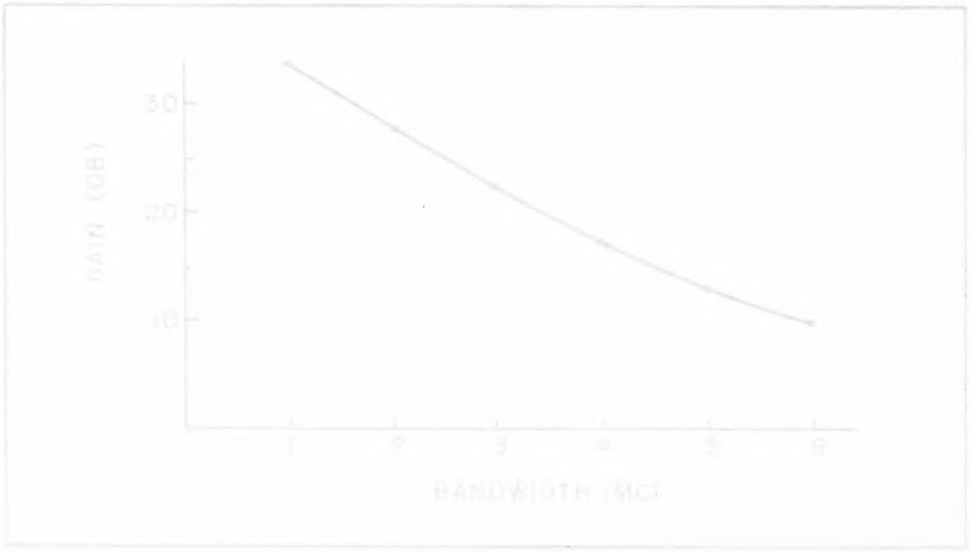


Figure 6

The complete curve may be constructed by calculating the low frequency maximum power gain which is approximately 1/(4 hib hob); for the 2N417, taken as an example, the low frequency maximum power gain is 41 decibels. This is shown in Figure 1 also.

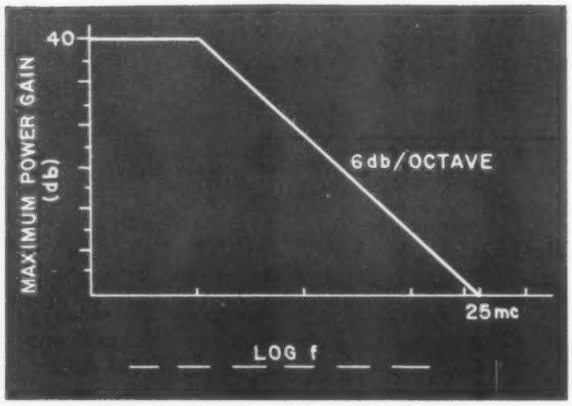


Figure 1

RF and IF Amplifiers

Transistor RF amplifiers are quite different in nature than RF amplifiers using tubes; the input and ouput impedances are much lower, and since the transistor is essentially a power amplifying device, matching is required for maximum gain. There is also an internal feedback path through $C_{b'c}$ which must be neutralized if regenerative effects are to be avoided. A typical circuit for an IF amplifier is shown in Figure 2. Cn is the neutralizing capacitor; its value depends on the turns ratio involved. It may also go from secondary winding to the base if the proper phasing is observed. This type of neutralization results in a neutralized amplifier, rather than a unilateralized one. It uses only capacitive feedback, whereas in order to obtain a unilateral amplifier, a resistance must be used either in series or parallel with Cn. The reason may be seen in the equivalent circuit, where a small conductance exists between collector and base terminals. For lower frequencies this difference is generally negligible and will not affect the results obtained; for higher frequencies a resistor may be required for proper operation.

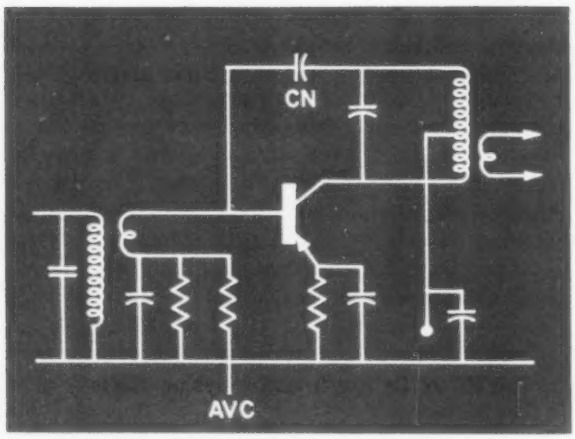


Figure 2

Another factor which must be taken into consideration when designing IF amplifiers for production is the normal variation in collector capacity, which may vary ± 2 $\mu\mu$f for a nominal 12 $\mu\mu$f unit. This variation, coupled with the variation in the neutralizing capacitor within its tolerance, would result in varying degrees of skewing of the bandpass characteristic, and, for extreme cases, might cause oscillation to occur. To account for the variations a deliberate mismatch of input and output impedances is achieved with a consequent loss in gain. In general, the loss in gain will be determined by the degree of skew which can be tolerated and by the deviation of collector capacity from its nominal value; the tighter the limits, the more nearly the useful gain will approach the maximum available gain.

Automatic gain control may be achieved through control of emitter current, base current, or collector voltage; emitter current control is most widely used since collector voltage control also affects collector capacity and thus causes detuning effects; control of base current is more critical of transistor parameters and may be affected by interchanging transistors. Typical variation of gain with emitter current is shown in Figure 3. Along with the variation in gain, the input and output impedances increase, causing the overall bandwidth to narrow.

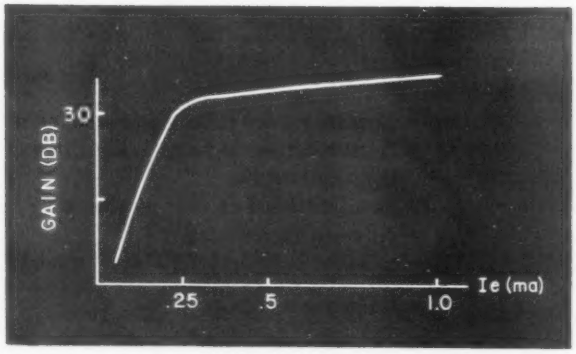


Figure 3

Wide Band Amplifiers

Techniques used in transistor wide band amplifiers are similar to those used in vacuum tube circuits. A useful figure of merit which may be used to determine

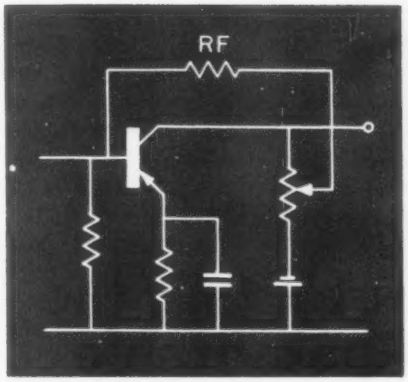


Figure 4

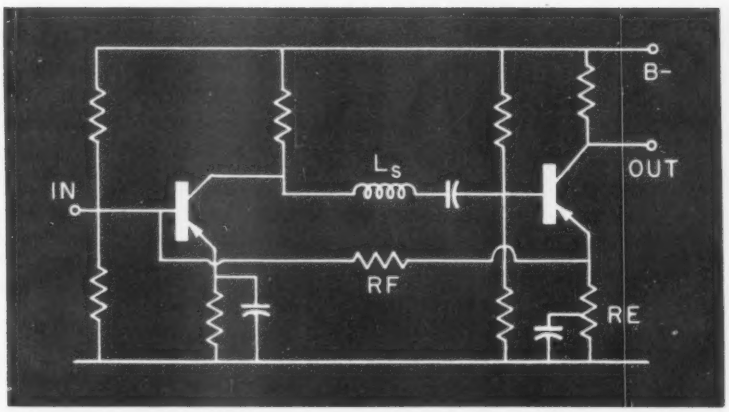


Figure 5

the approximate gain is $VG \cdot BW = \alpha_o f_{\alpha b}$ where VG and BW are single-stage voltage gain and bandwidth, respectively. Negative feedback may be applied from collector to base in a one-stage common emitter amplifier, as shown in Figure 4. A very stable two-stage circuit is shown in Figure 5. Feedback from second emitter to first base reduces the overall gain; the series inductance between collector and base extends the frequency response without affecting the gain. Typical results obtained using this circuit with two 2N417's for different bandwidths are shown in Figure 6; input and output impedances were 1000 ohms so that iterative operation of a number of stages is possible.

Most computer applications involve non-linear use of transistors in switching and pulse circuits. The response time of a pulse amplifier is primarily a function of the alpha cut-off frequency. Typical rise time for a Raytheon 2N428 with a 200 ohm load in a common emitter circuit is 0.4 microseconds. Rise time may be reduced by increasing the base driving input pulse. However, this method also increases the storage time, which is the time between the end of the input pulse and the knee of the transistor output pulse.

Storage time is due to an excess of minority carriers stored in the base region; a reduction of storage time may be obtained by maintaining a steady reverse bias at the base. Another method of reducing rise time without seriously affecting storage time involves the use of a speed-up capacitor of a few hundred $\mu\mu f$ placed across the series base input resistor.

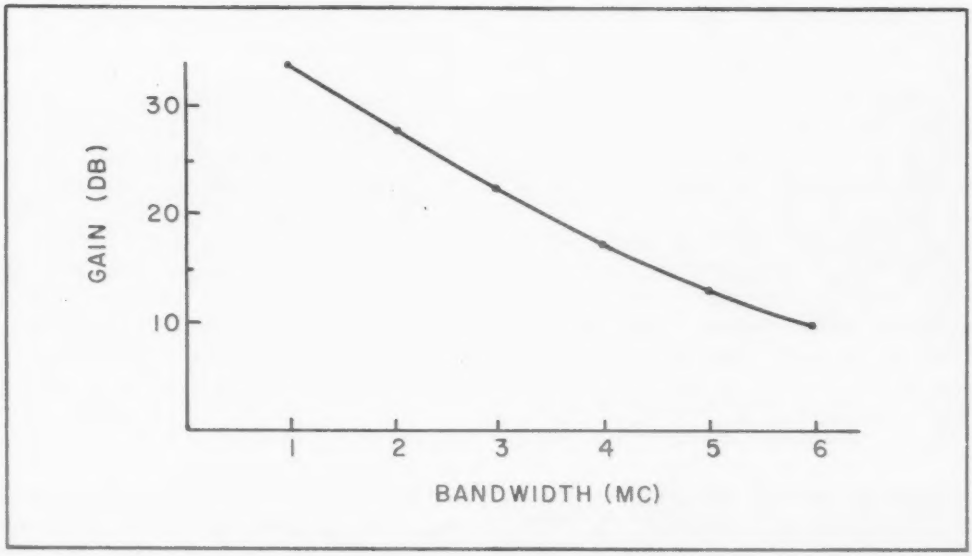


Figure 6

PATENTS

. . . protecting the unpatentable

B. Lemlein
Law Department

Previous articles in this series (Jan., 1958; Vol. II, No. 4 and May, 1958; Vol. II, No. 6) have dealt with the protection afforded patentable inventions under codified law, namely, the Patent Law. The present article will deal with the protection afforded trade secrets, sometimes called proprietary information or "know-how," whether patentable or not, under natural or common law, more specifically, the law of secrecy.

In its broadest sense, a trade secret may be defined as any information which would cost someone else time, effort or money to obtain unless he acquired it from the originator.

Although this definition may appear impractically broad, any information meeting its requirements obviously is property and, as such, has intrinsic value.

I have some information — You want it — It will cost you time, effort or money to obtain it if you try to do so yourself — Assuming I am willing to sell it, I should be permitted to place a price on it and if it is worth it to you, you should be willing to pay that price —.

Industry is generally guided by a more specific definition. In industry's view, a trade secret is any information concerning such areas as research, development, design, experimental, manufacturing or marketing activities, which information is neither generally known nor discernible from an examination of the product to which it relates, and may give to the owner an opportunity to obtain an economic advantage over third parties.

The following usually embody trade secrets:

a) Tools, dies, jigs, fixtures, patterns and apparatus for which unique designs have been generated and which are used in the fabrication of products, together with the drawings, design and fabricating specifications, use procedures, methods, devices and materials relating to such tools, dies, jigs, fixtures, patterns and apparatus.
b) Manufacturing, processing, treatment, finishing, assembling, testing and material specifications which are unique and which have been specially generated for use in the fabrication of products.

The creative act giving rise to an idea vests in the originator a property right for which he can either seek patent protection or rely upon the law of secrecy. If the idea is not patentable, he will have to rely on the law of secrecy. Even if it is patentable, he may decide against seeking a patent and take his chances with the law of secrecy.

Natural law gives to the creator of an idea the right to exploit it and the right to teach others to exploit it, but in the absence of the special circumstances mentioned below, he has no right to exclude others from similar exploitation. On the other hand, a patent provides this additional privilege.

Assuming the creator intends to treat his idea as a trade secret, the property right in his idea will persist as long as the information is kept out of the unrestricted possession of the public, and this may continue in perpetuity. However, if the secret is disclosed by the originator without restriction, or is legitimately discovered by another who has no interest in maintaining it as a secret, the originator's rights become forever lost.

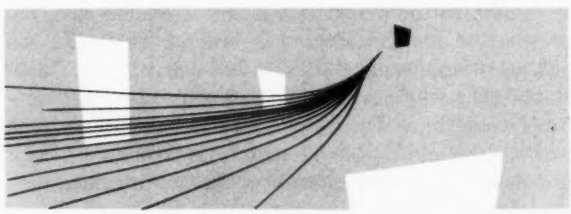
Not every disclosure results in the destruction of the originator's property right. As a matter of fact, disclosure may be made time and again, provided it is done under a pledge of secrecy or confidence, and for each

disclosure, the originator has the right to receive whatever compensation he desires and the recipient is willing to pay.

The rights of the originator of a trade secret may be violated in a number of ways. Unauthorized persons may learn the secret from the originator through the use of force or fraud, or persons to whom the originator communicated his secret in confidence may breach that confidence and improperly disclose the secret to others, or use it in a manner outside the conditions imposed at the time of the original disclosure. In any of these cases, the originator does not lose his secret; the Courts will enjoin its improper use and will, as well, award the originator compensation for whatever damages he may have suffered as a result of such improper use.

The independent discovery of an idea by a second "originator" who, like the true originator, wishes to keep it secret, is not a violation of the rights of the true originator, nor does it result in the loss of the rights of the true originator. Each is entitled to the enjoyment of his secret independently of the other and against the rest of the world. Furthermore, should a third party violate the rights of one of the originators, he is responsible only to the originator from whom he wrongly obtained the information; he owes nothing to the other. The act for which redress can be had is not the reproduction itself of the secret, but is the improper means employed in procuring it.

One who learns of another's secret through a third party, and who uses that secret with knowledge that its disclosure was unauthorized or mistaken, is responsible to the originator. A user who learns of another's secret without knowing that it is a secret, is not liable to the originator for any acts committed prior to notice of the secrecy. However, once he is given such notice, he is thereafter responsible unless, because of his change in position in good faith, it would be inequitable to penalize him.



There are many legal theories by which the owner of a trade secret may obtain redress for wrongful appropriation of his secret — express or implied contract, restitution, unjust enrichment, and breach of trust are examples. However, for such owner to succeed in a law suit in which violation of his trade secret rights is involved, he must satisfy the Court of the presence of the following four factual prerequisites:

1) The idea alleged to be entitled to protection as a trade secret must be *novel*, i.e., new to the person to whom disclosure is made,
2) The idea must have been reduced to a *concrete form*,
3) The idea must have been disclosed in *confidence* or under circumstances indicating an *expectation of compensation*, and
4) The party against whom relief is sought must have *appropriated* the idea.

Let us first consider the question of novelty.

A railway company agreed to pay a commission on receipts obtained from a plan by which it would sell advertising space in its stations, depots, cars, etc. The plan was carried out, but the railway refused to pay. In subsequent litigation, the Court held that the idea submitted to the railway was not original with the submitter but was a matter of common knowledge. The submitter had thought of nothing new and he therefore had no property right to protect.

A publishing company agreed to pay a percentage of the refunds it could obtain for overpayments of telephone excise taxes. There had been submitted to the company the information that a provision of the tax law exempted public presses from such taxes. The publishing company obtained the refunds, but refused to pay, contending that what had been disclosed was in the public statute and therefore was not novel. Suit was brought against the publishing company and the Court upheld the submitter. While the tax provision involved was obviously available to public inspection, it could not be said that such provision was common knowledge. Under these circumstances, something new and of value had been disclosed to the publishing company.

We will now consider the matter of concreteness.

An automobile manufacturer received an offer to suggest an improvement in its car, with an inquiry as to what compensation might be expected. The manufacturer replied that it would make no commitment without a full disclosure of the idea. The offerer then advised the company that its car sagged on one side and that this might be corrected by locating some of the equipment on the other side. No drawings or other details accompanied this suggestion. The company replied that redesigning the car was impractical. However, in later models, some of the equipment was relocated to distribute the weight more evenly. The offerer of the plan brought suit, but the Court held that not only was the idea not novel, but it was of no value to the manufacturer without its own necessary experimentation.

Another automobile manufacturer was offered a plan for certain improvements, mechanical and style-wise, with the understanding that if adopted, reasonable compensation was expected. This offerer had detailed drawings and other documents and specifications, and these were given to the manufacturer for study. Negotiations between the parties failed and the plans were returned to the offerer. In a new model of the automo-

bile, however, there was considerable resemblance to these plans. In a subsequent law suit, the Court held for the offerer. Although the automobile manufacturer denied it had purposely copied any of the plans, and it was proved that there were considerable differences as well as similarities, the Court recognized an unconscious assimilation which, however wanting in intent, constituted an appropriation of the salient features of the offerer's plans and a breach of trust under which the plans had been submitted.

We will next turn to the question of disclosure in confidence or in expectation of compensation.

A cigarette manufacturer received a letter in which there was described, in the following language, a billboard advertising scheme: "Two gentlemen, well groomed, in working clothes or in hunting togs, apparently engaged in conversation, one extending to the other a package of cigarettes, saying — 'Have one of these'; and the other replying — 'No thanks, I smoke Chesterfields.' " The letter expressed the hope that the idea would merit reasonable compensation. The manufacturer did not answer this letter. Nearly three years later, the manufacturer began an advertising campaign conceived by its advertising agency. Included in this campaign was a billboard showing two men in golfing attire with a caddy and golf clubs. One man was holding an open cigarette case and the other a pack of the manufacturer's brand of cigarettes. Beneath this picture was the statement — "I'll stick to Chesterfields." The letter writer brought suit and the Court upheld him. Although there was no confidential relationship here, the company never having answered the letter, there was an expectation of compensation.

A patent owner was negotiating with a manufacturer concerning a patent license. During the course of the negotiations, and in connection with a display of samples produced by the patented process, the patent owner incidently disclosed a decorative design which he specifically asked the manufacturer not to use. At a subsequent trade show, the manufacturer, in disregard of this request, displayed a product incorporating the identical decorative design displayed by the patent owner. Suit was brought and the patent owner recovered damages for all acts prior to the trade show. The Court stated that the manufacturer had been unjustly enriched as a result of his over-reaching and his taking of an unconscionable advantage. However, once the patent owner himself displayed the design, as he did at the trade show, there was an unrestricted disclosure which precluded recovery against the manufacturer for acts after the date of the show.

Contrast the last situation with the following:

An applicant for a patent licensed a manufacturer to make the device shown in a patent application, which was disclosed under circumstances giving rise to a confidential relationship. When the patent issued, the granted claims were considerably limited in scope and many of the claims originally applied for had been cancelled out of the application. The manufacturer refused to pay royalties on devices shown in the patent but not covered by the granted claims. He contended that the issuance of the patent was a publication with respect to all such devices and that, as of the date of issuance, these devices were open to free use by everyone.

In litigation between the parties, the Court said that the issuance of the patent did constitute a publication and everyone, that is, everyone except this manufacturer, was free to use any of the subject matter of the patent which was not within the protection of the granted claims. This manufacturer had received a disclosure in confidence and the Court would not allow him to breach that confidence, notwithstanding the publication.

Finally, we come to the matter of appropriation.

The New York World's Fair was furnished by an engineer with a color chart of the Fair grounds, including details of lighting, grouping, etc. The Fair Committee did not adopt this material, but used a plan which had been independently conceived by a member of the Committee. A comparison of the two plans indicated substantial differences. In a suit brought by the engineer, the Court decided in favor of the Fair on the ground that the Fair didn't use what had been disclosed to it by the engineer.

In another case, one party was a candy manufacturer and the other a wrapper manufacturer and printer. The first party developed a new wrapper and entered into negotiations with the other for the exploitation of the wrapper-making machinery. The machinery and the wrapper were disclosed in confidence. The prospective machinery manufacturer ordered a search of relevent patents and when one was found that was considered to control the situation, he bought it and broke off negotiations with the first party. In a subsequent suit, the prospective manufacturer was ordered to assign the patent it had bought to the first party. The Court stated that whether or not the prospective manufacturer would have discovered and purchased the patent without the information given to him in secrecy by the first party was of no importance; the fact remained that the disclosure of the information and its use as a basis for the search constituted a breach of confidence.

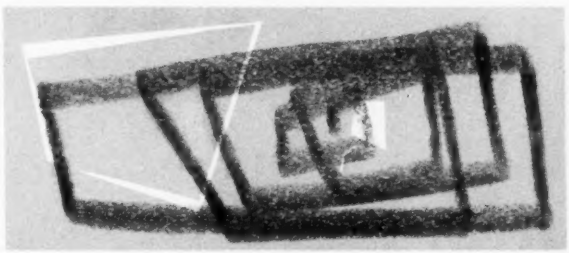
A company generally has to consider trade secrets that come from two sources, those generated within its own organization in connection with its normal business activities, and those submitted to it from the outside by third parties, sometimes solicited, but more often, unsolicited. A difficult problem that must be faced in connection with internally generated secrets is the

vigilant guarding against disclosure without the imposition of adequate restrictive conditions. A serious risk a company runs concerning trade secrets submitted to it from outsiders is inadequate protection against unwarranted claims for alleged improper appropriation of such secrets.

With respect to internally generated secrets, a company cannot too often remind its employees that such secrets are not to be communicated in any manner whatsoever to anyone other than responsible employees, unless such communication becomes necessary, for example:

a) In compliance with a specific contractual obligation requiring the furnishing of the secret,
b) To enable the normal use and maintenance by a customer of the company's product to which the secret relates, or
c) As an incident to a company purchase order to a supplier.

In all of the above situations, the recipient should be required to maintain the secret in confidence.



Companies having trade secrets that are reduced to writing or other graphic form can assist themselves in guarding against loss of their rights by providing all copies thereof with an appropriate legend, of which the following is an example:

"This document contains proprietary information of The X Company. It shall not be published, reproduced, copied, or used, in whole or in part, for any purpose without the express written permission of a duly authorized agent of the Company."

Ideas submitted to a company from the outside, especially if unsolicited, can give rise to embarrassing situations. While it is not always easy to avoid such situations, it is necessary to do so in the interest, among other things, of good public relations.

Companies obviously should deal with submitters with all the respect and fairness to which they are entitled. At the same time, and especially inasmuch as it is well known that juries usually favor the "little man" suing the "big corporation," the company must take such protective measures that should the submitter and the company be unable to get together, the company will be in the same position as it would have been had it never heard of the idea.

Submissions are of two kinds; one consists merely of an offer to disclose an idea and the other consists, right at the outset, of the disclosure itself. The former gives the company an opportunity to fix the conditions under which it is willing to consider the idea; the latter obviously reduces to some extent the company's freedom of action. Both require the utmost tact.

One way a company might proceed in the first situation is to explain to the submitter before any disclosure is made, that proposals by outside parties, however well intended, can lead to unfortunate misunderstandings unless the conditions of submission are defined, in writing, in advance. After so explaining, the submitter might be asked to agree to the following, for example, which might be helpful in avoiding subsequent unpleasantness.

"The X Company will be glad to consider any descriptive material on the subject of your (appropriate identification) which you may wish to present upon the understanding (1) that this material will not be considered as having been disclosed in confidence, (2) that our examination thereof will be for the purpose of permitting us to determine, in our sole discretion, whether we may wish to negotiate for any rights therein, and (3) that in the event we decide not to negotiate for any rights, or that any negotiations which we may enter into fail to produce a satisfactory arrangement, there shall be no obligation of any nature whatsoever on our part."

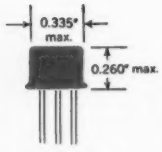
In the second situation, the disclosed idea should not, in the initial stages, even be looked at by any of the company's operating personnel. Instead, the submitter, again after explanation of the desire to avoid misunderstandings, should be advised that the company will be happy to consider the submitted material upon his agreement to the conditions set forth above.

In view of the hazards associated with outside ideas, companies should impress upon their employees the desirability, if approached in this connection, to consult with the company's legal advisors before giving the matter any consideration.

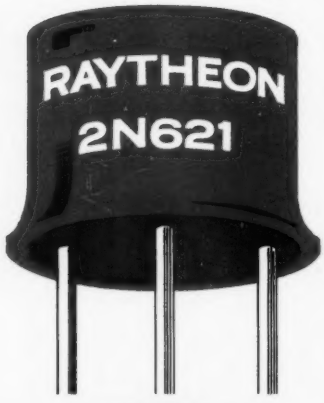
NPN as well as PNP...only RAYTHEON offers both

RAYTHEON

New NPN SILICON TRANSISTORS



actual size



NEW RAYTHEON NPN HIGH TEMPERATURE SILICON TRANSISTORS

Type	Reverse Current at −20V		Beta	Base Resistance ohms	Collector Resistance kilohms	Noise Figure db(max.)	Collector Capacity μμf	Alpha Freq. Cutoff KC
	Collector μA	Emitter μA						
2N619	0.005	0.005	14	2000	500	30	35	200
2N620	0.005	0.005	25	2500	500	30	35	350
2N621	0.005	0.005	50	2700	500	30	35	500
2N622	0.005	0.005	20	2400	500	15	35	300

RAYTHEON PNP HIGH TEMPERATURE SILICON TRANSISTORS

Type	Reverse Current at −20V*		Beta	Base Resistance ohms	Collector Resistance kilohms	Noise Figure db(max.)	Collector Capacity μμf	Alpha Freq. Cutoff KC
	Collector μA	Emitter μA						
2N327A	0.005	0.005	14	1200	500	30	65	200
2N328A	0.005	0.005	25	1400	500	30	65	300
2N329A	0.005	0.005	50	1500	500	30	65	400
2N330A	0.005	0.005	18	1300	500	15	65	250

All ratings are for 25°C. For all types: Dissipation Coefficient in air, 0.4°C/mW; infinite sink, 0.25°C/mW.

- made by the **reliable Fusion-Alloy** process
- suitable for complementary circuits
- **low saturation voltage**
- good emitter efficiency to high currents
- temperature range: −65°C to +160°C

RAYTHEON SEMICONDUCTOR DIVISION

Silicon and Germanium Diodes and Transistors • Silicon Rectifiers

Newton, Mass......55 Chapel St., Bigelow 4-7500
New York:.....589 Fifth Ave., PLaza 9-3900
Chicago: 9501 Grand Ave., Franklin Park, NAtional 5-6130
Los Angeles: 5236 Santa Monica Blvd., NOrmandy 5-4221

Printed in U.S.A.